AD NUMBER

AD890544

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and evaluation; 19 Nov 1971. Other requests shall be referred to Chairman, Department of Defense Explosives Safety Board, Washington, DC, 20314.

AUTHORITY

ONR ltr, 26 Oct 1977

AD 890544

Thirteenth Annual

Explosives Safety Seminar

Minutes

El Cortez Hotel, San Diego, California 14-16 September 1971

AD No. ____
DDC FILE COPY

The Armed Services Explosives Safety Board

Washington, D. C.

709

MFR: The Armed Services Explosives Safety Board is now called the Department of Defense Explosives Safety Board. ab

19 JAN 1972

ACCESSION for

NTIS	WHITE SECTION ☐
DDC	BUFF SECTION ☑
UNANNOUNCED	☐
JUSTIFICATION	

DISTRIBUTION/AVAILABILITY CODES

DIST.	AVAIL. and/or SPECIAL
B	

MINUTES

THIRTEENTH ANNUAL

EXPLOSIVES

SAFETY SEMINAR

EL CORTEZ HOTEL

SAN DIEGO, CALIFORNIA

14 - 16 SEPTEMBER 1971

DEPARTMENT OF DEFENSE

ARMED SERVICES EXPLOSIVES SAFETY BOARD

WASHINGTON, D. C. 20314

TABLE OF CONTENTS

WELCOMING ADDRESS

Colonel William Cameron III, USAF
Chairman
Armed Services Explosives Safety Board

Good morning ladies and gentlemen. Welcome to the 13th Annual Explosives Safety Seminar.

This is my second year as sponsor and I am extremely pleased at seeing so many of you back again this year. I wish to extend a special welcome to all of those attending for the first time.

We have an excellent program with topics of interest to all. These presentations, seminars, and discussions will work for the common good of our profession worldwide. This is the bond that brings all of us to San Diego.

The theme chosen this year "Safety in a Changing Environment" was not selected aimlessly. Really, when you think about it, everything we do "is" or should be dictated by the rules of safety. From the rubber non-skid mat in the shower in the morning to the Bakelite knob on the lamp you turn off at night, all spell safety. For a moment let us look around this room. Draperies are treated to prevent fires as well as the carpeting and paint on the walls. In other words, there is a safety rule for everything in our environment. This is especially true in the field of explosives. I do not have to remind you that in our special area everything is dictated by considerations of safety, or at least should be.

Now the other part of the theme - the word "change." Change is inevitable. Every day we change. Every day we must change. It is time to think change in our profession. We will talk more on this subject as the seminar progresses.

Before I go further, let me stop before I completely pre-empt our keynote speaker. I can think of no one better qualified or more competent to discuss our theme. Our speaker entered Federal Service in 1933 and from that day till this he has built a reputation for outstanding performance that is unmatched in the Federal Service. His entire career has been devoted to improved management of Federal programs. He has the headaches - construction, properties, installations. In DOD he is the landlord - in fact some call him the Czar of Housing. Since 1961, he has been Deputy Assistant Secretary of Defense (Installations and Housing). Ten years in an environment that has been constantly changing make him especially qualified to discuss any aspect of our theme. It gives me great pleasure to introduce to you Secretary Edward J. Sheridan.

SAFETY IN A CHANGING ENVIRONMENT

Edward J. Sheridan
Deputy Assistant Secretary of Defense (Installations & Housing)

Thank you Colonel Cameron. Admiral Williams, General Olds, ladies and gentlemen. It is with distinct pleasure that I accepted Scotty Cameron's invitation to attend this seminar.

The Explosives Safety Board is doing a wonderful job and these seminars are an excellent method of exchanging information and increasing our effectiveness in the very important field of safety.

The theme of this years seminar is safety in a changing environment. Certainly we are in a very rapidly changing environment and it would be possible to speak for several hours on these changes and their effects on safety and us here today. However, rather than speak to you myself on these matters, I have brought with me an expert from my staff - and you all know we define an expert as someone who knows when to talk and what to say to keep the boss happy - to discuss the theme.

Mr. Howard Metcalf is an expert on the environment and on safety and he will now address you on Safety in a Changing Environment.

Mr. Metcalf, you may now speak for several hours.

PRECEDING PAGE BLANK

SAFETY IN A CHANGING ENVIRONMENT

Howard L. Metcalf
Office, Deputy Assistant Secretary of Defense (I&H)

Thank you Mr. Sheridan. Colonel Cameron, ladies and gentlemen from industry, Government, the academic world, distinguished representatives of other governments, members and friends of the Armed Services Explosives Safety Board. It is indeed a great pleasure to address the Thirteenth Annual Explosives Safety Seminar.

These seminars began in 1959 at the Naval Propellant Plant, Indian Head, Maryland, as a "Solid Propellant" seminar to exchange ideas on how to improve safety in the solid propellant field. The subject area of the seminars was gradually expanded to include liquid propellants and high explosives.

The need for such seminars covering the entire explosives area was recognized, and the job was being performed so well by these gatherings that in 1968 they were expanded to be simply "Explosives Safety Seminars" as they are today. Those of you who have attended previous seminars are cognizant of their high value, and I am sure that for any of you who may be attending your first session this value will become evident well before this seminar concludes.

The Armed Services Explosives Safety Board, now in operation for over 40 years, has a distinguished record as the oldest military organization devoted exclusively to the objective of saving lives and preventing damage. This objective is of importance not only to the military personnel who must use our weapons, but to the industries who produce and transport them and, of course, to the public at large. The Armed Services Explosives Safety Board has served all of these interests fully and well.

Since a large portion of the work of the Armed Services Explosives Safety Board involves the facilities in which weapons are to be stored and the land around them required to provide proper safety clearances, and since we are in the business of building facilities and buying land, it was considered logical to place the Board in Mr. Sheridan's organization -- in the Office of the Deputy Assistant Secretary of Defense for Installations and Housing, affording the Board direct access to the Secretary of Defense.

Under a Department of Defense Directive, the Board operates as an almost independent agency. The day-to-day operation of the Board and its Secretariat is entirely the responsibility of the Chairman. As many of you know, Deputy Secretary of Defense Packard's philosophy of management includes the concept that if you want a job done, pick a good man, tell him to do it and then keep out of his hair.

PRECEDING PAGE BLANK

There has been no time when that philosophy has been better proven than in the case of Colonel Scotty Cameron, the present Chairman of the Board. Since assuming that position a year and a half ago, Scotty has brought a dynamic and positive force to the Board which it has never previously approached. The Department of Defense and the United States are fortunate in having him in this position.

I mentioned a word with respect to the Board's operation and that word was dynamic -- the theme of this seminar is Safety in a Changing Environment -- change and dynamics -- two words with almost the same meaning. The Board or any other organization involved in safety cannot be responsive to our changing requirements without a dynamic program of change itself. What was acceptable or "good enough" yesterday will not meet tomorrow's requirements, and it may not be good enough today.

You all know of our increasing concern with the environment. The concern itself is not new -- conservation organizations have existed for decades. Certainly, one of the Government's most ardent conservationists was President Theodore Roosevelt whose term of office ended over 60 years ago. Research of U.S. laws finds many concerned directly with protection of the environment enacted in the 1800's. What is new is the emphasis.

And let me say that one of the most emphatic groups in the country today are the environmentalists--be they Nader's Raiders or the Sierra Club -- they are sincere, they are emphatic and they are vocal -- and they have brought to the forefront of the country's attention a degree of concern with the environment never paralleled before in human history.

What have been the results of this concern so far? What are future results likely to be? How will they concern us, and what must we do to be responsive to these changing attitudes? I cannot answer these questions fully and completely here this morning, and all of us together collectively probably could not. However, we may review what has happened so far, and speculate upon the future.

Certainly those of you involved in production are familiar with the Clean Air Act and the Water Quality Act. Ammunition plants by the very nature of the substances involved in production -- nitric and sulphuric acids among others -- could be, if not controlled, among the worst contributors to pollution in the nation.

Government-owned ammunition plants were nearly all old and outmoded during the time of the Korean conflict, let alone the current Southeast Asia situation. As such, they poured tons of nitric acid, sulphuric acid, nitrogen oxides, sulphates, and sulphites into the nation's air and water each day.

Fortunately, at about the same time that concern with the environment was increasing, it was also recognized that these plants were becoming

uneconomical and unsafe to continue in operation. Hundreds of millions of dollars were being programmed and spent for their modernization.

Here it was only reasonable to design these modernizations to include pollution abatement features. More efficient use of materials, recycling, reclaiming and reusing materials will not only provide for more efficient and less costly production, but will permit treatment of wastes to the extent that current air and water antipollution standards will be met.

We cannot relax even here, however, for there is always the possibility that future studies will indicate that even more stringent standards should be adopted, and our best plants today may be less than adequate next year. And it is not often that a plant modernization program will be so well timed.

What about you commercial producers who have a plant which does not meet an existing or proposed air or water pollution standard and which is uneconomical to upgrade? This is indeed a serious situation. Executive Order 11602, signed by the President on 30 June of this year in implementation of the Clean Air Act, provides that the Administrator of the Environmental Protection Agency shall publish and circulate a list of facilities and persons who have been convicted of a violation under Section 113(c)(1) of the Act.

No Federal Agency can then enter into any contract for procurement of goods, materials or services to be performed wholly or in part in a facility so designated as long as it remains on the list. Removal from the list is dependent upon a finding by the Administrator that the condition which gave rise to the conviction has been corrected. It is therefore vital to your interests, as well as ours, that every effort be made to correct these situations as soon as they are discovered.

Why have I dwelt so long on antipollution laws? Because the basic objective of these laws is safety -- SAFE air for people to breathe -- SAFE water for them to drink -- and protection from radical changes to the ecology of an area when we do not know what effect these changes will have on the totality of man's environment.

Which brings us to another important recent law -- the National Environmental Policy Act. This Act requires that before a Federal Agency takes any action which could have a significant effect on the environment or which may be controversial as to its effect on the environment, an environmental impact statement must be prepared.

This statement will address in detail any and all aspects of the proposed action which will affect the environment, what these effects will be, what can be done to minimize them, alternatives to the proposed action (including not doing it), and all of these in extensive detail. These statements will be made available to other agencies, Federal, State, and local, and to citizens groups and individuals for comments.

These comments must receive full and adequate consideration before proceeding with the proposed action. Actions which will require environmental statements will range from the acquisition of a few acres of land to the major procurement of new weapons.

This does not necessarily add more time to our procurement process because statements may be processed concurrently with our normal budget review and programming actions -- but it does add work.

This is especially true in the Department of Defense where, as you know, we have been undergoing reductions in personnel for some time. And it adds work for you in industry if, for instance, the proposed actions involved a product produced in a plant that would need to be discussed in the environmental statement.

And it adds work for all of you here who may be at any time involved in a proposed new action to be taken. It is logical that the man at the bench or desk who first has the idea is the first person who must address the environmental impacts of that idea. They must be studied and considered by all persons in the approval chain above him.

And any action, almost without exception, even if it does not require an environmental impact statement, will require somewhere along the line that a determination be made and documented that such a statement was not required.

As I said, it adds work -- but nobody ever guaranteed that our jobs would be easy -- and the eventual result should be a great improvement in the environment and the quality of life for all of us -- and for the generations to come.

The previous laws and the Executive Order I have discussed are general in nature, but we have had recent laws and policy changes which have been directed specifically at military weapons and material.

A recently proposed law (which the Department of Defense opposes) would require us to determine in advance of the procurement of any material, precisely how long that material can be safely retained in stocks and precisely how the material would be disposed of at the end of that time. Further, the language in which that legislation is proposed would apparently make it apply to everything -- from potatoes and overcoats to explosives and chemical weapons.

Another recently proposed law (which we also oppose) would make it illegal to transport, store or dispose of chemical weapons. Perhaps the drafter had in mind disposal by sea dumping, but the language did not specify the manner of disposal, only that it was prohibited. Should this pass, we could neither keep what we have nor could we get rid of it.

Legislation such as this we oppose as being basically unworkable, but we do note that it indicates a tendency by many in the Congress to place tighter and tighter restrictions on our actions and to further circumscribe the areas in which we have freedom of action to provide for the essential Defense requirements of the Nation.

Believe me, gentlemen, if I said the job was getting harder, it is going to get much harder.

Some of you may be familiar with Public Law 91-121, as amended, which prohibits the Department of Defense from taking any action to transport to new areas or to dispose of chemical munitions unless full details of the proposed actions are presented to the Secretary of Health, Education and Welfare for his review to assure that the public health and safety are not endangered.

I am sure you know that the plans for disposal of our biological weapons stocks (ordered by the President for disposal two years ago and now in progress) had to be reviewed by HEW, the Department of Agriculture, the National Academy of Sciences, State officials, and many others before we could proceed.

I am sure you are also aware that the Secretary of the Navy ordered a suspension of deep water dumping of unserviceable ammunition until complete and thorough studies of previous deep water dumps and their effects, if any, on the marine environment could be completed.

What is the Department of Defense doing to comply with all of these recently imposed requirements? Naturally, we are involved in a major program touching almost all of our installations to comply with air and water quality standards -- and we are processing environmental impact statements for our major actions.

However, and fortunately so, in the past 4 years we have taken certain administrative actions with respect to the Armed Services Explosives Safety Board which are directly in accordance with environmental objectives.

First, we required that the Armed Services Explosives Safety Board review and approve all plans for new ammunition storage sites prior to a request for funding of those plans by the Military Departments involved. This action has been particularly effective in bringing the expertise of the Board into the early planning stages of projects to assure the safety of all, within and outside of storage reservations.

Then we extended the field of interest of the Board, traditionally limited to explosives, fire and fragment hazards, to include the safety aspects of chemical and biological weapons. (And let me again note that we are in the process of disposing of our biological weapons.) Without going into detail, I will state that the Board's entry into this field has produced results which are, to say the least, dramatic.

Thirdly, we consolidated the research program in munitions safety -- previously fragmented among several agencies -- into one program directly under the Board. This research is currently funded at $500,000 per year, and the program has already produced data resulting in substantial changes to our safety standards and in the design of our storage structures. Other changes in the Board's responsibilities and functions will be made as they become necessary to further our safety programs. A change now in process will add representation from the Defense Agencies to the Board and will change the Board's name to Department of Defense Explosives Safety Board to reflect this wider participation.

One of our major current problems is disposal of obsolete or unserviceable munitions now that the sea dumping option is no longer available to us. Many weapons in the past have not been designed with disassembly and demilitarization in mind. Disassembly of these weapons is a difficult and highly hazardous operation. It costs time, money and sometimes lives. Open air detonation is still permissible in some cases, but since it releases large amounts of nitrogen oxides and other undesirable compounds to the atmosphere, this avenue may also be closed to us in the future.

The Department of the Navy has recently reviewed their specifications for shells, and I understand that they have now adopted a policy whereby the design of all future shells will allow for relatively easy disassembly. While this will permit a simple method of demilitarization of the shells, the problem of disposition of the explosives will remain.

It has been suggested that biological decomposition may be practical in many cases and would be a cheap, easy and safe method. Many other speculative and innovative ideas will be necessary for evaluation in the future.

Disposal is, of course, only one problem area. We have had accidents at all stages in the life cycle of munitions. Production, transportation, storage handling, testing and use -- all have seen their share of unfortunate events. New ideas, new methods, new procedures -- each of which contributes to increased safety -- will be required throughout these areas.

And if we who are in the business do not meet these challenges, we shall find ourselves more and more being dictated to by others who are not so well informed. The results of such a situation could only be to make a difficult task more difficult, or even impracticable.

Let me summarize. We in the Department of Defense have one job to do. We must provide the men, material and arms necessary for the Nation's security. And we must provide these resources within the constraints -- budgetary, environmental or otherwise -- established by the people through the Congress. You in industry have a similar task. You must, to remain in business, produce profitable and salable products within similar constraints.

To do this, we must develop methods of production, storage, use and disposal which are neither hazardous to the people involved in these operations, nor which result in unacceptable degradation or pollution of the environment. The ideas for the method by which we will attain these objectives must come from all levels, from the worker on the production line to the lawmaker appropriating funds.

Only by the participation and active involvemement of people at all levels will we be able to continue our work successfully as it becomes increasingly more complex and more challenging in the years ahead.

Thank you.

THE AIR FORCE'S EXPLOSIVES ACCIDENT PREVENTION PROGRAM

Brigadier General Robin Olds, Director of Aerospace Safety
Colonel John L. Gornall, Chief, Explosives Safety Branch
Mr. D. E. Endsley, Supervisory Officer, Explosives Safety Branch
Mr. F. G. Henderson, Explosives Safety Officer, Explosives Safety Branch
Directorate of Aerospace Safety
Deputy Inspector General for Inspection and Safety
Headquarters, U. S. Air Force
Norton Air Force Base, California

Mr. Sheridan, General and Flag Officers, ladies and gentlemen. We do appreciate this opportunity to meet with such a distinguished group of professionals who, day-to-day, contribute so much to the savings of life and property. We might ask, "Why should safety be given so much attention?" "Isn't it just another necessary evil?" "Accidents are going to happen, so what else is new?" They say that one picture is worth a thousand words - we have a short film clip to show you.

We will give you some historical background, cover our organization and its relationship within the Air Staff, explain the purpose of the accident prevention program, and some of our responsibilities. We will then discuss subjects pertaining to safety engineering, education and training, inspection and accident experience.

The Air Force Explosives Accident Prevention Program is required by public law and a Department of Defense Directive which charges each of the Military Services with maintaining a continuing, aggressive accident prevention program throughout all its commands. It further requires that adequate safety organizations be provided to insure a directed and effective accident prevention program. We have three basic documents which implement the public law and DOD Directive.

The Chief of Staff has charged the Inspector General with the responsibility for administering the USAF Aerospace Safety program. The Inspector General is located at the Pentagon.

The Deputy Inspector General for Inspection and Safety at Norton Air Force Base, California, implements the safety program through the Directorate of Nuclear Safety at Kirtland Air Force Base, New Mexico.

Our Directorate of Aerospace Safety is organized into two divisions -- one being Systems Safety and Engineering and the other, Safety Operations Division. Flight, Ground, Explosives, and the Missile and Space Safety Branches are in this operations division. These two divisions manage the Accident Prevention Programs and are supplemented by the Safety Education, Reporting and Documents, and the Life Sciences Groups. In addition, officers from the Air National Guard,

PRECEDING PAGE BLANK

Air Weather Service, United States Navy, foreign governments, and personnel from the Federal Aviation Agency, and industry representatives are present for coordination and liaison.

Each commander from major command through wing and base level, or separate operating squadron, is responsible for implementing a comprehensive and aggressive explosives accident prevention program. The purpose of which is to conserve the combat capability of the Air Force through the preservation of its personnel and materiel resources, and to achieve the maximum in explosives accident prevention, consistent with operational requirements. Our mission is to prevent all accidents -- the acceptable number of accidents is zero, and to minimize fatalities, damage and destruction, in the event of an explosives accident.

We in the Explosives Safety Branch strive to insure that all related explosives operations are conducted in a safe manner and that those nonnuclear munitions, associated test and handling equipment and procedures in use, or proposed for use, meet the highest safety standards consistent with design, logistical and operational requirements throughout their life cycle. We work closely with and enjoy the full cooperation of the System Safety and Engineering Division.

Safety must be designed and built into weapon systems if they are to be reliable and effective. Reliability should include everyone and everything that goes into making a system work properly and safely in the hands of the operator. If there is any doubt about this rationale, this film strip should highlight these needs.

These are examples of the mishaps we encounter during testing and which we strive to eliminate prior to operational use. These events caused losses of military resources, both in terms of material and human lives. It is obvious then that safety must be considered as important as any other facet of weapon system development.

The degree of safety achieved in a military system is directly dependent upon management emphasis. Emphasis on safety must be applied by Government and contractors during the conception, development, production and operation of each weapon system.

One of the most significant contributions that has been recently added to the Air Force Explosives Safety Program is the System Safety Engineering concept. We call this "Before-the-fact-accident-prevention." This method helps eliminate expensive modifications and loss of lives associated with, waiting for the smoking hole, and then determine what caused the accident. Military Standard 882 provides general requirements and criteria for establishing and implementing system safety programs and guidelines. It requires that the contractor establish and maintain an effective system safety program that is planned and integrated into all phases of system development.

production, and operation. These requirements are applicable to all contracts for every system being developed for the Air Force, including nonnuclear munitions. The System Safety Engineering concept is simply identifying the hazards of a munition during the design phase and eliminating or controlling these hazards before the hardware is built. The Air Force has, over the years, placed ever increasing emphasis on its accident prevention program. The conventional facets of the approach were:

(1) Personnel training and education

(2) Use of safety surveys and inspections

(3) The analysis of information from accidents

(4) Maximum use of safety literature

While this program in all its elements has been effective, these basic accident prevention approaches should not be curtailed but reinforced. Application of system safety engineering principles are the strongest reinforcements available to attain the zero accident objective.

New solutions and continued efforts are required to further reduce the loss of resources.

In approximately 40 percent of all Air Force accidents, design deficiency has been a contributing factor. A design deficiency is any failure of the total system, including the munition. This includes not only hardware design, but the related operational procedures. Overall Air Force accident data indicate that for the period 1967 through 1970, design deficiency accounted for at least 350 million dollars in hardware losses.

Although total accident frequency has been decreasing, the percentage chargeable to design deficiencies has remained almost constant over the past ten years. This is significant and an area of genuine concern. System safety engineering is an area where progress can and is being made in reducing accidents. Although its full potential has not yet been achieved.

The Air Force test and evaluation program is in two phases; acquisition testing, and operational test and evaluation. Acquisition testing includes system and subsystem development test and evaluation and follow-on development test. Operational test and evaluation is a functional area under the control and direction of operating commands. Normally, the using command conducts employment tests in support of its assigned mission. They test to improve capability and usage, develop tactics, techniques and procedures, define operational problems, and new requirements and modifications.

New and modified systems or support items, including conventional munitions, nuclear weapon systems and associated equipment are tested and evaluated during their acquisition to determine that they are:

(1) technically sound

(2) reliable, and

(3) safe for Service use, designed to be as free as possible from deficiencies or procedures that could cause personnel errors in operations or maintenance.

As we have shown, all testing does not proceed as planned. Occasionally, a disaster occurs, but in most instances we avoid or quickly eliminate the deficiencies. Now you will see a good missile and a smart bomb.

Now we will cover some of our other projects.

In order to provide a disciplined procedure for the safety evaluation of munitions and components, we have established a formalized safety study and review program. The objective is to insure that nonnuclear munitions, associated test and handling equipment and procedures meet the highest safety standards consistent with design as well as logistical and operational requirements throughout their life cycle.

General Olds is responsible for providing overall Air Force policy and guidance for the Nonnuclear Safety Study and Review Effort. However, the focal point of the safety study and review program is the Air Force Nonnuclear Munitions Safety Group. The Group is one of the most important activities in the Air Force today to promote before-the-fact explosives safety.

To give you an idea of the impact potential of this Group and why we consider the Group is so important, let us show you a part of AFR 127-100.

With a charter such as this, and the responsibility to assure that each new item is subjected to a most critical safety review, we are sure the Group will attract considerable interest. This is especially true since the Group reviews encompass <u>all</u> munitions and components used by the Air Force.

This vugraph depicts the Group as currently organized. The Group consists of qualified personnel representing the major commands. These are the personnel who thoroughly review the Technical Munitions Safety Study of the munitions being evaluated. A study may originate from two sources. If a development item is involved, Air Force Systems Command will prepare the study and chair the meeting. If an inventory item is to be reviewed, Air Force Logistics Command is responsible.

After a thorough review and consideration of all safety implications, the Group will approve the study, or disapprove it if it does not meet established safety standards.

The safety report, including group recommendations, is provided to us at Norton for review and coordination with interested Air Staff offices. When approved, the recommendations in the report are directive in nature. Further development, test, procurement or use, sanctioned by the group, may then proceed. Otherwise, all, or specific actions must cease until corrective action is taken.

We believe the success of the Nonnuclear Munitions Safety Group will clearly manifest itself in the saving of lives, equipment, and other resources.

We have initiated several tests which involved the storage of explosives, and parking and protection of combat aircraft - the most recent was "Concrete Sky," a test of shelters used in SEA. These structures have proven successful in Vietnam against hostile mortar and rocket fire.

One phase of the project considered the safety problems associated with the accidental detonation of a fully loaded aircraft within the shelter. We wanted to know if an explosion would propagate into adjacent shelters, causing near simultaneous detonations.

This test was initiated because of the problem in SEA where we had a high-density parking situation as shown on this vugraph. The siting of shelters in full compliance with DOD explosives quantity-distance requirements exceeded the land areas available. We needed to learn if these shelters would prevent propagation should an explosion occur. If the test indicated that rapid propagation of explosions to adjacent shelters were prevented, then the quantity-distance requirements could be relaxed with confidence.

These shelters were of the standard double corrugated steel arch design, 48 feet wide at the floor, and covered with 15 to 18 inches of concrete. Here is a view of two methods of Southeast Asia shelter separation representing arrangements as far as side-to-side protection is concerned. Shelters separated by the 5¼-foot thick, 12 foot high, earth filled, steel barricade provide a great deal more protection than those without barricades. This is a rear view of the test using three shelters; note the barricade arrangement. The center shelter was the donor. The barricades across the rear and between the two shelters are visible. The other shelter was separated from the donor by the usual 6 to 12 inches. The donor floor was of standard 6-inch thick concrete which extended eight feet into the adjacent shelters, to provide for normal reflections during the explosion and to anchor the adjacent shelter walls in the usual manner.

The obsolete aircraft in each shelter were fully fueled and loaded - with wing tanks and twelve 750 pound bombs containing a total of 4632 pounds of high explosives. The load was arranged to simulate an operational F4. The center shelter bomb load was detonated and the effects were recorded by high-speed photography and air pressure gages.

Large fireballs jetted out the front, rear, and top of the shelter but did not sweep around into adjacent ones. Also there was no evidence of excessive heat or fire in adjacent shelters. Not the shotgun effect, fore and aft.

The center shelter was totally destroyed. Bomb and aircraft fragments were projected primarily out the front. Most fell within a 30 degree arc as far away as 1200 feet along the centerline.

Along the edges of the bounding angle, furthest fragments were at about 850 feet. The rear barricade was destroyed, but it limited projection of high speed, low angle fragments. Blocks of concrete, ranging from pebble size to 6 foot pieces, were found over a large area.

The side barricade tilted against the right shelter. The right shelter near wall was displaced about 6 inches but otherwise relatively intact. The left shelter near wall moved inward up to 6 feet. The location of the maximum displacement corresponded to the location of the bombs in the donor shelter.

Associated with the displacement of the base was the hinging action in the curvature of the wall. This rear view of the left shelter illustrates the separation of concrete on the exterior.

Surviving aircraft have not been subjected to a structural analysis; however, damage did not appear to be extensive, beyond some wrinkling of the skin on the fuselage.

This is a back view of the overall site. This test indicated the following:

(1) Unbarricaded shelter structures in side-by-side arrays will prevent "simultaneous" detonation and provide reasonable protection against propagation of the explosion, where explosives weights do not exceed 4800 pounds.

(2) Increased explosives loads could collapse unbarricaded side-by-side shelters.

(3) Side barricades materially reduce shelter damage and propagation.

(4) Propagation could occur where open ends of nearby shelters face each other.

(5) Nonsimultaneous propagation could occur in shelters placed back-to-back against current steel bin barricades. The barricade should prevent high speed, low angle shrapnel from reaching the bombs in the back shelter.

Many of you are familiar with the term hazard classification which is defined on this vugraph. The DOD Instruction and implementing directives are also shown. As far as the Air Force is concerned, we have been following the "conservative approach" in assigning hazard classifications to assure that

appropriate safety is provided. We also keep the munitions and transportation communities informed.

Let's move on to human engineering. When we develop a new item, major consideration is given aerodynamic design parameters and performance capability. It is easy to overlook the fact that munitions must be conceived and produced by people, maintained and serviced by others, and its use directed by different people. Equipment sometimes fails because of materiel breakdown or because of aerodynamic misconceptions; however, a major factor in accidental losses is failure on the part of some human. If accident-free experience is to be achieved, the human engineering factor must receive major consideration. The errors of one generation of equipment are too often carried on to another, while good design features are sometimes lost.

Because man is a system component, human performance is considered an integral part of total system performance. The consideration of human engineering requirements must begin in the concept formulation of the system life cycle. It is important that alternative man-machine interface design concepts be analyzed and evaluated. This insures that the equipment design, human tasks and the working environment are compatible with the attributes of the personnel who will operate, maintain, control, or support systems and equipment.

We will discuss some of the areas where history has indicated that care must be taken if accidents attributable to human error are minimized.

Airmen continue to blow off aircraft canopies by actuating the emergency escape system to open the canopy, instead of operating the push button actuator for normal cockpit entry. The emergency system is marked "rescue," with another decal reading, "Pull handle to jettison canopies," and this is exactly what some airmen do. Equipment is designed to be stable, highly reliable, and fundamentally easy to operate by at least an average, trained operator. This term "average" is of considerable importance. If equipment is designed to the average, this means that some will operate it well; others marginally. The only way in which maximum safety can be achieved is to design it to the lowest level of the known user group.

Jettison buttons are sometimes located in close proximity to other switches and are inadvertently operated while the pilot is concentrating on other elements of a mission. In combat aircraft particular attention should be given to the design and location of ordnance release switches. There should be little possibility of inadvertent release.

A similar problem involved a switch that fires an explosive bolt to release the barrier hook. The simple lesson learned was that a switch guard should be installed.

In another aircraft, loading personnel were required to position their bodies between bombs being loaded in the bomb bay. It was recommended that a new system be developed. This hazard should have been avoided during the design. In addition, munitions have been manufactured that are impossible to maintain. An example was a smooth, round nut that was particularly difficult to install or remove.

We must keep in mind "Murphy's Law" -- that if something can be done wrong, somewhere, sometime, someone will do it. Little can be done to modify human limitations; therefore, they must be recognized during design and development.

Although the discussion of technical orders may be considered a dry subject by some, they are a keystone of the Air Force safety program.

They are the official media for disseminating technical information, instructions, and safety procedures pertaining to the operation, installation, maintenance, and modifiation or updating of Air Force equipment. They play a critical role in achieving system and equipment readiness. Safety planning for technical orders to support a system and associated equipment must begin during the concept phase of research and development. Technical order data are procured for delivery before or concurrently with the equipment. A schedule is formally imposed on contractors to meet these requirements, phased to acquisition and delivery of munitions to the Air Force.

The technical orders most referred to are the munitions aircraft loading technical manuals. These contain descriptive data, and the safe and reliable procedures for loading munitions on, or into our aircraft. They provide step-by-step procedures in proper sequence. We have integrated manuals for loading and delivery of two or more different types of munitions with due regard to whether the munitions are nuclear, nonnuclear, or combinations. We also have manuals for the inspection, issue, handling and storage of nonnuclear munitions. Compliance with Air Force technical orders is mandatory.

Occasionally there are errors, or data are omitted which are necessary to complete an operation safely. Therefore, any person discovering a deficiency requiring changes to a technical order must initiate an improvement report.

Explosives safety is strongly dependent on the quality of individual items, and when quality decreases costs and hazardous conditions increase. For example, in 1968, 976 explosives mishaps were reported. Of these, approximately 440 or 45 percent were attributed to material failure or malfunction. The 1969 and 1970 statistics were similar. So far this year we are continuing at a rate of 44 percent.

The reported accidents and incident involved quality of design or production. From seemingly insignificant items such as an arming wire safety clip, which resulted in high explosives bombs becoming completely armed during captive flight, to total loss of an aircraft and crew because of fuze premature

functioning. The arming clip condition was caused by inadequate quality control during heat treating and stress of this seven cent item. The fuze failure appeared to result from inadequate safety analysis, poor design, and inadequate quality control during production.

Some new munitions components have been unsafe, and incompatible with the end item. Some were:

(1) Threads not machined properly on bomb adapter boosters.

(2) Incomplete or misaligned threads on components.

(3) Improperly machined fuze delay cavities.

(4) Improperly drilled holes in fins.

(5) Fuzes indicating an armed condition when removed from the shipping container.

(6) Base plates not securely welded to bomb bodies, and fin adapters out of round.

These unsatisfactory items were not loaded on an aircraft. What really concerns us are the ones that could have, or did contribute to the loss of aircraft, personnel, and property. We will review some of them:

(1) Several fuzes armed during aircraft loading operations; the investigations revealed manufacturing defects.

(2) Air crews returning from combat missions have reported, as duds, numerous bombs with retarded fins. The duds were caused by failure of the fin to open after release, or loss of the fins.

It is obvious that some of these conditions are alarming to our pilots, particularly when they drop a bomb at low altitudes and the retarding device fails to function, not allowing the aircraft to clear the lethal envelope. This jeopardizes our aircraft and degrades our capability to support ground forces, sometimes in immediate need of air support. We are looking for a more reliable fin assembly. Here, we do need the help of industry.

Although we are concerned about the safe transportation of explosives including shipments by vehicle, rail, and water, we in the Air Force are primarily concerned with air shipments. We are intimately involved in the safety of Air Force and contract aircraft and the passengers and cargo. We will discuss some problems.

One is the improper labeling, marking, and packaging of explosives being shipped to and returned from Southeast Asia. As an example, during less than a three-week period, movement of 391 tons of dangerous cargo was frustrated at one base because of these discrepancies. This problem not only created hazards, but also overloaded storage facilities and disrupted the flow of the materiel.

The biggest problem this year has been a considerable increase of incidents reported in which passengers have carried or shipped contraband explosives on aircraft. These occurrences jeopardize the safety of passengers, crew, aircraft, and terminal facilities.

Military Airlift Command and contract carriers transport large numbers of personnel. This aircraft had just arrived from Korea. At our passenger terminals there are amnesty boxes. These containers are available for personnel to deposit all explosives contraband with no questions asked. Contents are removed after each departure and arrival.

This photograph depicts the customs inspection at the port of U.S. entry. When contraband explosives are found the inspection really slows down. The hold baggage is also inspected.

This is a sample of the items found. The crossed items are made of primers from something like a 105 shell, with a cartridge case on one end and a 30 caliber bullet on the other. The flower vase was made from a 40mm shell, but the primer is still live. Included are small arms rounds and rifle grenade cartridges.

Recently, it was reported that one individual brought in 116 rounds of ammunition, 114 signals, and 41 flares. We have also found high explosives in baggage. Such items as hand grenades, talcum powder cans filled with plastic explosive, and in another case, a belt around the individual's waist containing a quantity of plastic explosives, with the blasting caps to complete whatever operation the individual may have had in mind.

An individual's orders specifically stated that firearms, ammunition, and explosives items were restricted from luggage, yet a small arsenal was found in his hold baggage. In some cases, personnel were unaware of prohibitions against such transport, or the seriousness of the hazards involved. Frequently they abandon the explosives contraband in or near the terminals. Through publicity in safety media and assessment of personnel processing procedures, all of us can actively contribute to reducing incidents such as these.

We have solicited the support and assistance of the other Services in preventing the unauthorized movement of explosives aboard passenger aircraft.

To give you an idea of the magnitude of the problem, here is a list of the items recovered. You will note that some of these items would cause a big "bang" - and early unscheduled flight termination. Here are some more.

During the past ten years the Air Force has transitioned from an environment of isolated explosives storage areas and relatively nonhazardous flightlines to our highly complex, explosives loaded aircraft on ready launch bases. This has evolved with considerable acceleration in the past six years. However, personnel, support equipment, base facilities and environments have not easily adjusted to these requirements.

The advent of the Vietnamese conflict brought on numerous explosives safety problems. Bases were not capable of storing the large amounts of munitions essential to their missions. For example, huge amounts of mass detonating explosives were stored in a single stack.

Hardstands for storage and roads within the areas were nonexistant. This created hazardous conditions in handling and storage.

Storage areas were often located too close to runways, barracks, aircraft, and other airdrome facilities.

Existing barricades were not adequate to reduce the number of fragments produced in case of an accident.

This vugraph shows the high loss potential which existed on flight line areas with explosives loaded aircraft nearly wingtip to wingtip.

A study of these problems was made in 1966. Early in the study it was recognized that high speed fragments impinging on adjacent stacks of bombs be the most likely cause of near simultaneous detonations from one stack to another and that barricades would be necessary to reduce these hazards.

The study recommended a storage configuration incorporating standard earth barricades and reduced quantity-distance criteria, as shown at the top. At the bottom, the previous criteria are also shown. The study also recommended tests to validate these new configurations.

The test known as "Big Papa" was required to confirm our calculated minimum separation between barricaded stacks of bombs in the 125 thousand to 500 thousand pound range. These tests confirmed that the storage module configurations would provide the degree of safety required. This was a life saver to the Air Force, and one which the other Services have adopted. We immediately sited and constructed these facilities which could contain a maximum of eight cells with a total of two million net pounds of explosives.

Further, explosives safety hazards on the flight lines were reduced by the construction of the metal-clad, earth-filled barricades. Under enemy fire, or in accidents, these structures have minimized the loss of personnel, aircraft, and facilities.

Explosives safety is maintained by product improvements through isolation and correction of deficiencies identified. The correction of deficiencies affecting mission accomplishment are given precedence according to their impact on safety and reliability. We have a system for identifying and reporting such materiel deficiencies.

Field activities emphasize the importance of complete and accurate reporting of hardware performance at unit level. This improves the ability of management to identify serious deficiencies and to expedite fixes. Emergency unsatisfactory materiel reports are required on all deficiencies in nuclear safety, critical, or explosives safety hazards, and mission failures.

Munitions people have at best a spotty record in this area. For example, one command repeatedly reported a deficiency involving a bomb lift clutch and drive train, until they got bomb lifts with a new transmission. Our depot advised that this was not a widespread problem but solely due to that command's particular operation, but during a visit to other bases we found the same problem. This was a classic example of the squeaking wheel getting the oil. Due to the lack of reporting, the depot was not aware of the magnitude of the problems.

Air Force Aerospace Safety includes the Explosives Safety Education Program, and provides promotional material in the interest of accident prevention. This includes educational media such as films, various publications, and other materials.

We are particularly proud of the 32 page "Aerospace Safety" magazine and the "Ground/Explosives Safety Officer's Kit." Aerospace safety covers both operational and maintenance activities. Accident prevention information on flight, ground, missile, and explosives safety is included in the 50,000 copies printed each month. About 5000 of these copies go to subscribers outside the Air Force.

The Ground/Explosives Safety Officer's Kit contains safety articles, commercial publications, pamphlets, and related safety material. It is published every other month, alternating with the Flight Safety Officer's Kit. Approximately 4,500 copies are distributed to Air Force organizations.

The "TIG Brief," a semimonthly publication, provides commanders and staffs authoritative information of direct concern to the operational effectiveness of the Air Force. It covers anticipated and actual problem areas; deficiencies; recommendations to improve management; policy guidance; safety, inspection, and operational techniques; and outstanding practices and procedures -- all to make it an excellent management tool.

Major commands also have publications providing similar information to their units.

We have produced a number of explosives safety films. Our latest entitled "How to Behave in Jeopardy," should be released soon. It portrays the behavior of the careless, over confident, frightened, and the moody, and relates these to explosives safety. The use of these films will enhance our accident prevention program.

From Inspector General initiative, Air Training Command is combining missiles, explosives, nuclear and ground safety accident prevention management training into one course. A graduate will be qualified across the board in safety concepts and program management.

On a trial basis, we have also included explosives accident prevention management in the Ground Safety Course conducted by New York University.

We perform explosives safety surveys in Southeast Asia, monitor inspections by major commands, visit operational units, commands, AMAs and industry. However, the greater part of our field effort is participation in Unit Effectiveness Inspections known as UEIs. These inspections cover safety and all other areas impacting on mission capability to provide the Chief of Staff a continuous sampling of the overall effectiveness of Air Force units.

Each UEI team is headed by The Inspector General or one of our General officers from Norton. The teams are tailored to the needs of each specific inspection. From January through July 1971, my eight project officers participated in 28 such no-notice inspections.

These hard hitting UEIs generate renewed vigor by unit commanders and headquarters staffs to remove causes of deficiencies.

The application of explosives safety principles and criteria must be before the fact. A closely integrated munitions safety effort is imperative, and much has been accomplished. We are not satisfied or complacent. We intend to build on what has been achieved thus far. Violations of good safety practices have resulted in a series of events leading to an explosives disaster such as this one at Da Nang.

If we are fortunate enough to control and minimize the extent of damage in the first event, we should count our beads and redouble our efforts to avoid the dispa aging accident that attracts loads of "crushing" attention, such as this one did.

An evaluation of explosives accident reports indicated that many of the accidents were caused by personnel and supervisory errors. This factor can be broken down further - it reflects lack of command emphasis, inadequate supervision, improper attitude, and noncompliance with technical data. It

frequently is a symptom of our failure to recruit and train experienced munitions and explosives safety personnel in the lean years and, hence, our later inability to cope with a rapid buildup. This is when a busy commander needs an old experienced head to provide persistent, gutty advice on how to avoid needless disasters.

We have experienced three accidents involving 750 pound bombs while being prepared for missions. In each accident three men were killed when munitions personnel pushed bombs off a stack. Investigation concluded that local munitions personnel were of the opinion that bombs would not detonate by falling such a short distance.

A weapons mechanic was wounded when a round fired from one of the aircraft guns. He had reached inside the cockpit of an OV-10, pulled the trigger and shot himself. He failed to follow technical data or to use common sense.

An airman was fatally wounded while the load crew was performing a functional check of a 20mm gun pod on an aircraft. Investigation revealed that the load crew chief did not insure that all checklist steps were performed, or in their proper sequence. Improper attitude and behavior resulted in one man killed, one injured, and major aircraft damage.

Two EOD Sergeants had been burning unserviceable 20mm ammunition. During cleaning of the burning pit, one of the Sergeants found two live rounds and handed them to the other Sergeant. A few seconds later they exploded resulting in severe injuries. The complete operation was attempted in one afternoon; however, the regulation specified that at least 12 hours cooling time was required before inspecting the pit. All these accidents show a disregard for compliance with Air Force explosives safety requirements. Since the rapid buildup which began in 1965, the Air Force has received, stored, transported, loaded, and expended millions of tons of munitions, costing several billion dollars. Explosives accidents resulted in 23 Air Force fatalities and property losses of nearly $20 million, including some aircraft.

Under the prevailing conditions, this may have been an acceptable record for the multitude of exposures to accident potential; however, we are not content or satisfied with these results. Stress on facilities that minimize and limit explosive propagation, good training and supervision, combined with strict adherence to high quality technical data, have made our explosives operations safer than most any other activity of equal magnitude. Personnel error continues to be a major cause of explosives mishaps. Accordingly, those individuals who cannot discipline themselves to adhere to sound explosives safety practices must be eliminated.

In summary, we have presented the highlights of the Air Force Explosives Accident Prevention Program. Tragically, 10 personnel were killed during 1969 in explosives accidents; there were four fatalities in 1970, and

regrettably, one has been killed this year. Our objective is no fatalities. During inspections and surveys we have noted renewed efforts in accident prevention programs. System Safety has taken an active part in the development of weapons systems; and human engineering has also assisted. Perhaps our collective efforts are paying off, but we are not yet satisfied. We have been striving to abide by some fundamental principles of explosives safety:

First, we must have high quality and safe munitions. Next, we must have proper facilities and equipment.

Also, we must have reliable technical data. Then we must use the minimum number of personnel, all trained for each operation, exposed to the lowest level of hazard; for the shortest reasonable time; at isolated and uncluttered locations; using the proper, serviceable and calibrated tools, proper equipment and checklists; under qualified and hardnosed supervision; in an environment of command emphasis on safety. These fundamental principles remain constant and the penalty for ignoring them can be explosively disastrous.

In closing, we say the importance of advanced planning and the application of the fundamental principles of explosives safety, coupled with a thorough knowledge of the explosives materials being handled, cannot be overemphasized. Gentlemen, that concludes our presentation.

OPENING REMARKS FOR
REVIEW OF CURRENT EXPLOSIVE
SAFETY STANDARD EVALUATIONS
ESKIMO I - IGLOO TEST

by

LTC John D. Coder, USA
ASESB

Our program for the next one year and a half will be to informally review with you some of the more significant R&D projects the ASESB is currently sponsoring. The theme of our current R&D effort is to focus on the critical voids that exist in our explosives safety standards and to initiate R&D projects that will produce immediately usable data. In this regard I would like to mention that when a project candidate is being considered, we first attempt to determine if any of the Services have an on-going R&D effort in the area that we are considering, and this is why continuous dialogue between the multitude of R&D activities of the Services and contractors must exist with our Secretariat, who beside myself, make up our R&D team. Mr. Perkins from Washington State University has been with the ASESB since 1946 and provides invaluable experience and expertise relative to what's been done in the past and where we should be going in the future. Dr. Zaker from Illinois Institute of Technology joined the Board in early 1970 and augments the R&D team with formal scientific training and over 15 years of experience in explosives effects and safety. As for myself, I provide the needed assistance in dealing with the military laboratories and to insure that what we do is responsive to the Chairman's desires.

Before starting with our program I would also like to indicate that although we encourage questions we do have a tight schedule; therefore, after each presentation we shall have a limited question period and in the event more time is needed for a project we will remain after the session for additional discussion.

The first item of our agenda involves the ESKIMO I test. ESKIMO is an acronym for explosives safety knowledge improvement operation and this task involves igloo separation distances. Russ Perkins and Mr. Fred Weals from China Lake will give a brief synopsis of this project. Our next subject fragment hazards to personnel will be discussed by Dr. Zaker and Mr. Feinstein of IITRI. Sequential explosion experiments is our next topic. Recent experimental results will be described by Mr. Jim Swatosh of IITRI. And in conclusion Mr. Don Allen of Arthur D. Little will describe recent experimental work aimed at improving our ability to predict weapon sensitivity to fragment impact.

PRECEDING PAGE BLANK

ASESB IGLOO SEPARATION TEST

ESKIMO I

by

Mr. R. G. Perkins, ASESB

Mr. A. R. Sound, China Lake

The magazine separation standards of the DOD require separation distances which are sufficient to preclude the communication of an explosion from one magazine to another. The surest means of preventing this communication is to utilize steel or concrete arch type magazines with earth cover. The minimum separation permitted between the earth covered surfaces of two adjacent igloos is 1.25 times the cube root of the contained weight of explosives. If, however, the unprotected headwall of a steel arch igloo faces the earth covered side of another, the separation distance requirement is 4.5 times the cube root of the weight as shown in Figure I.

The reason for this larger separation factor for the unprotected headwall is that, in past evaluations of magazines, lesser distances were never proof tested for this orientation. The side-to-side separation was adequately proof tested with a 100,000 pound maximum test in the configuration shown in Figure II.

Current land acquisition problems and high costs make it desirable for the separation distance from an igloo headwall to the next adjacent igloo to also be reduced to the minimum which is acceptably safe. The separation distance factor of 4.5 times the cube root is considered to be quite conservative and possibly excessively costly in terms of real estate acquisition.

As can be seen from this Figure III, for larger quantities of explosives the real estate savings will be very considerable if many igloos are planned for a given location. The Board is planning a full scale evaluation test of these igloo separations to complete the series which originally permitted adoption of the steel arch igloo as a standard. The final configuration of the test area is as shown in Figure IV.

The donor igloo will contain a nominal weight of 200,000 pounds of high explosives. Acceptor structures will be positioned as shown to evaluate the indicated separation distances for this amount of high explosive. Based upon the multiplication factors and conventional cube root scaling, this information can then be used safely for the siting of magazines containing larger or smaller amounts of high explosives.

The donor to be used is a steel arch magazine which remained from the last prévious igloo evaluation test. Figure V is a pre-shot view of that test.

The donor charge will consist of palletized 155mm projectiles stored in accordance with the applicable Army Materiel Command standard storage drawing. The igloo will be physically filled. This storage is illustrated by Figure VI.

In addition to the igloo separation distances, this test will provide an opportunity to study the dispersal of fragments and the blast pressures from such an explosion. No experience is available indicating the results of a detonation of high fragmentation ammunition such as this in the standard earth covered igloo. Observations will be made of blast overpressure and fragment and debris density. The locations of blast gages and fragment collection space areas are shown in Figures VII and VIII.

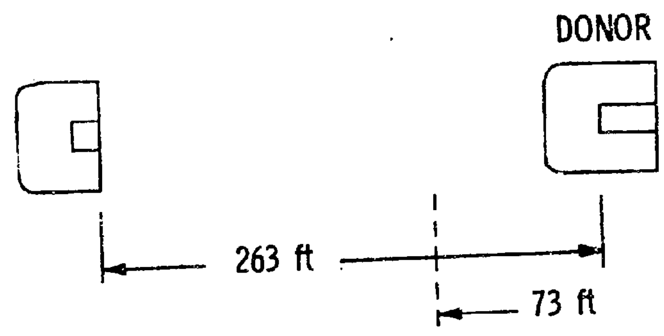
It is planned that fragment pickup areas will be cleared completely of the metal fragments from the projectiles and concrete and steel fragments from the magazine. These fragments will be classified into weight groups in order to provide estimates of impact energy and concentration at various locations for evaluation of quantity-distance standards to protect personnel.

Blast pressure measurements will permit additional correlation of static resistance of the headwall with its response to high intensity blast loadings of relatively short duration. A surplus B-29 aircraft will be positioned in such a manner as to give a measure of the hazard to aircraft should such an explosion occur near airfield operating facilities.

Very little data is available for pre-shot estimates of the results. There is a possibility that the headwalls of acceptor structures may be driven inward with sufficient velocity to initiate explosives positioned behind them. The anticipated results are that the two acceptors located at $2.0W^{1/3}$ may be considered acceptably safe and that the only one which is in real danger of a catastrophic failure is that one located at $1.25W^{1/3}$.

This test is tentatively scheduled for the period between 15 November and 15 December 1971 at the Naval Weapons Center, China Lake, California.

PROBLEM: EXISTING DOD STANDARD



W = High explosive weight in pounds

$$W = 200,000$$

$$W^{1/3} = 58.5$$

$$\text{Distance} = 4.5\,(W^{1/3}) = 263 \text{ ft}$$

FIGURE I

1963 IGLOO SEPARATION TEST

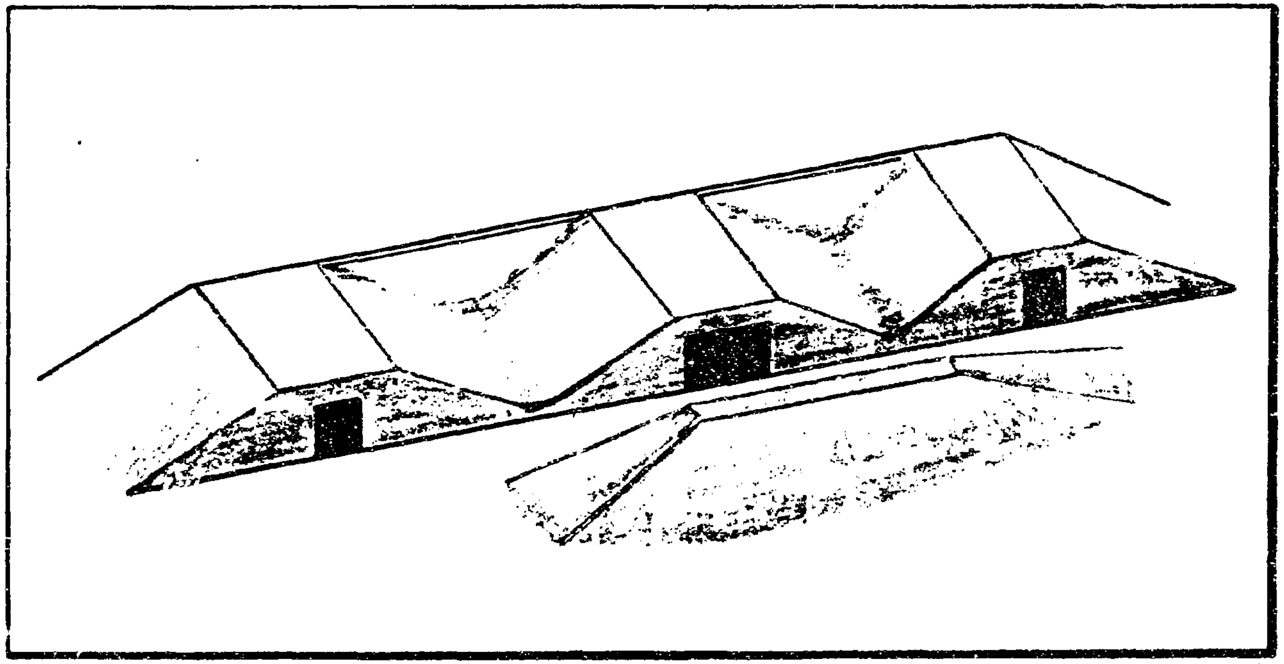


FIGURE II

DISTANCES FOR 200,000 POUNDS
OF EXPLOSIVES

$1.25 \times W^{1/3} = 1.25 \times 58.5 = 73$ feet

$2.0 \times W^{1/3} = 2.0 \times 58.5 = 117$ feet

$2.75 \times W^{1/3} = 2.75 \times 58.5 = 161$ feet

$4.5 \times W^{1/3} = 4.5 \times 58.5 = 263$ feet
(Present DoD Standard)

Obvious Potential for Real Estate Saving
if the Eskimo I Test Demonstrates Safety
at Any of the Lesser Values

FIGURE III

LAYOUT OF TEST STRUCTURES FOR ESKIMO I
ASESB IGLOO SEPARATION TEST

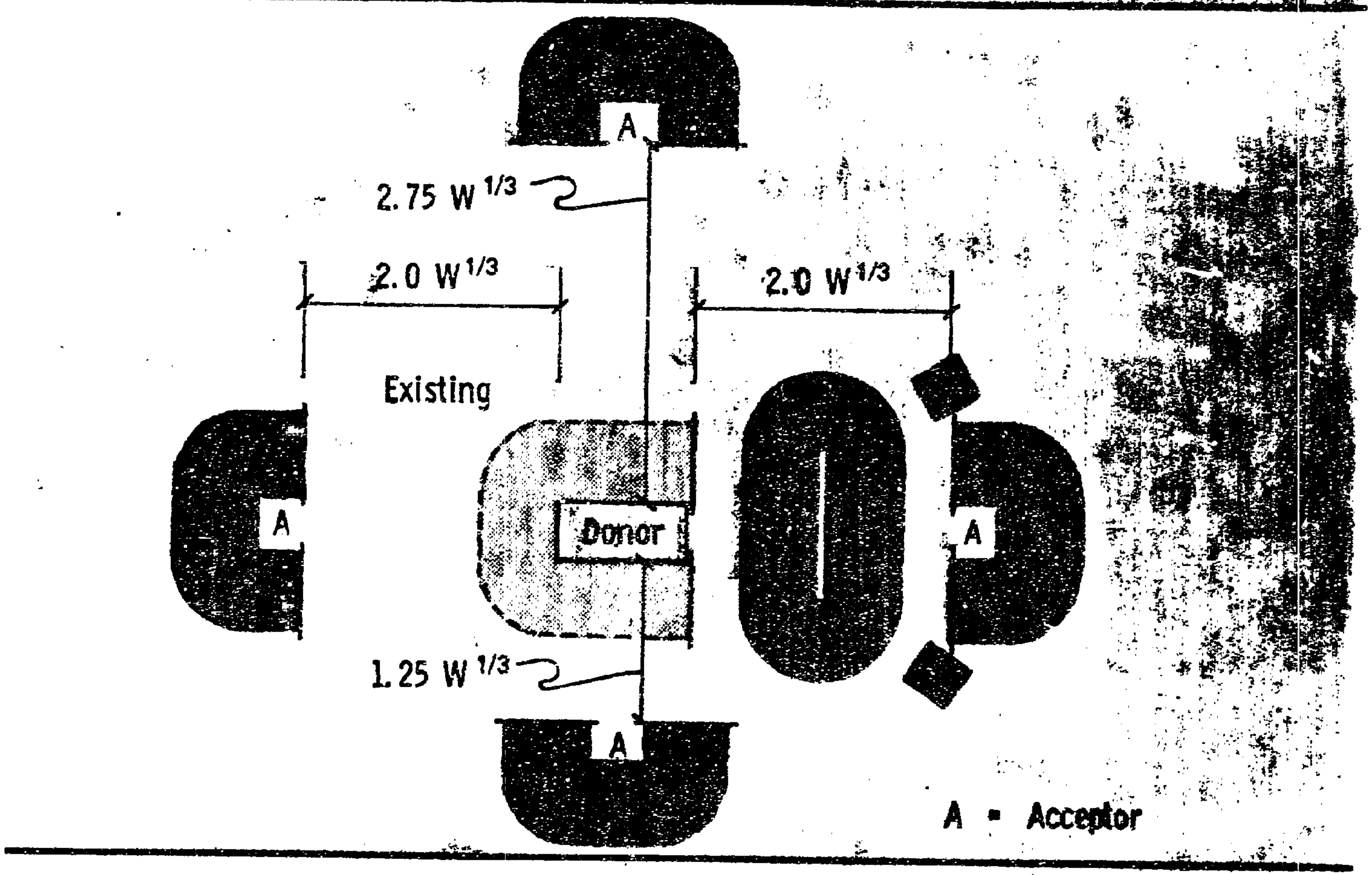
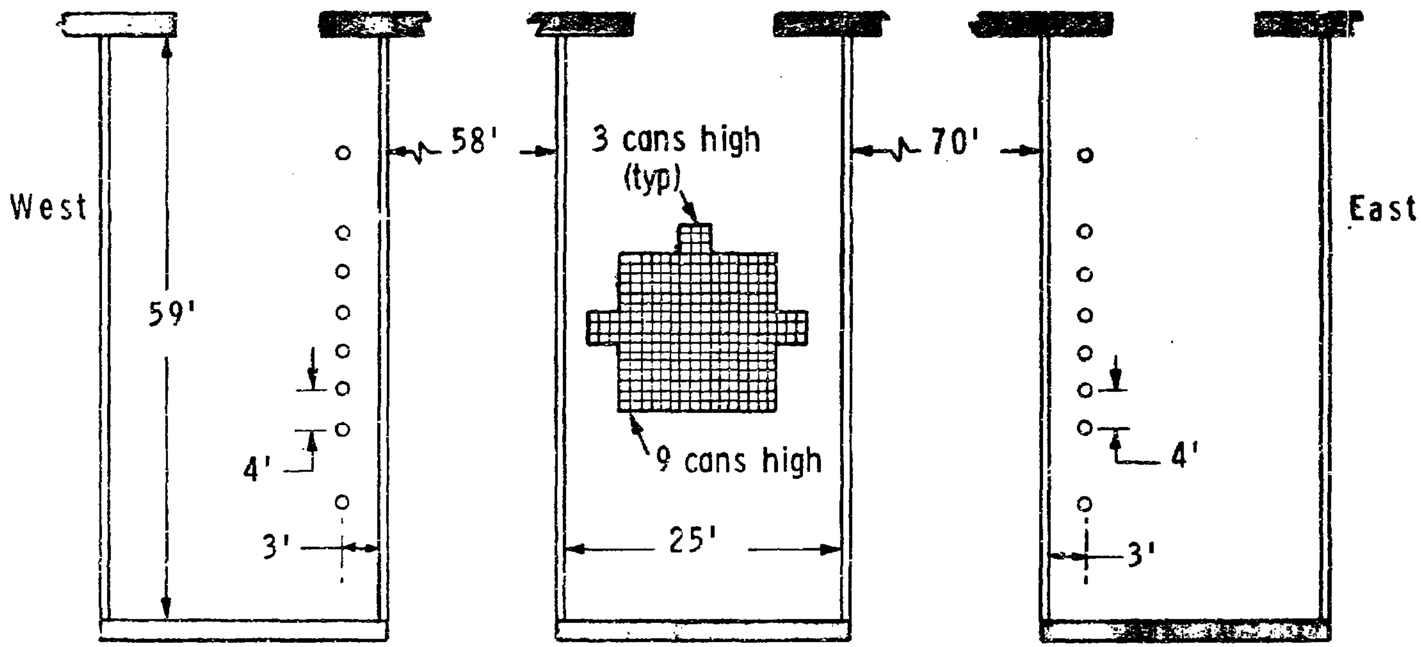


FIGURE IV

1963 IGLOO SEPARATION TEST



LEGEND:
- ○ Acceptor charges
- ▫ Donor charges (at 47.5#/can=2106 cans)

FIGURE V

STORAGE DIAGRAM

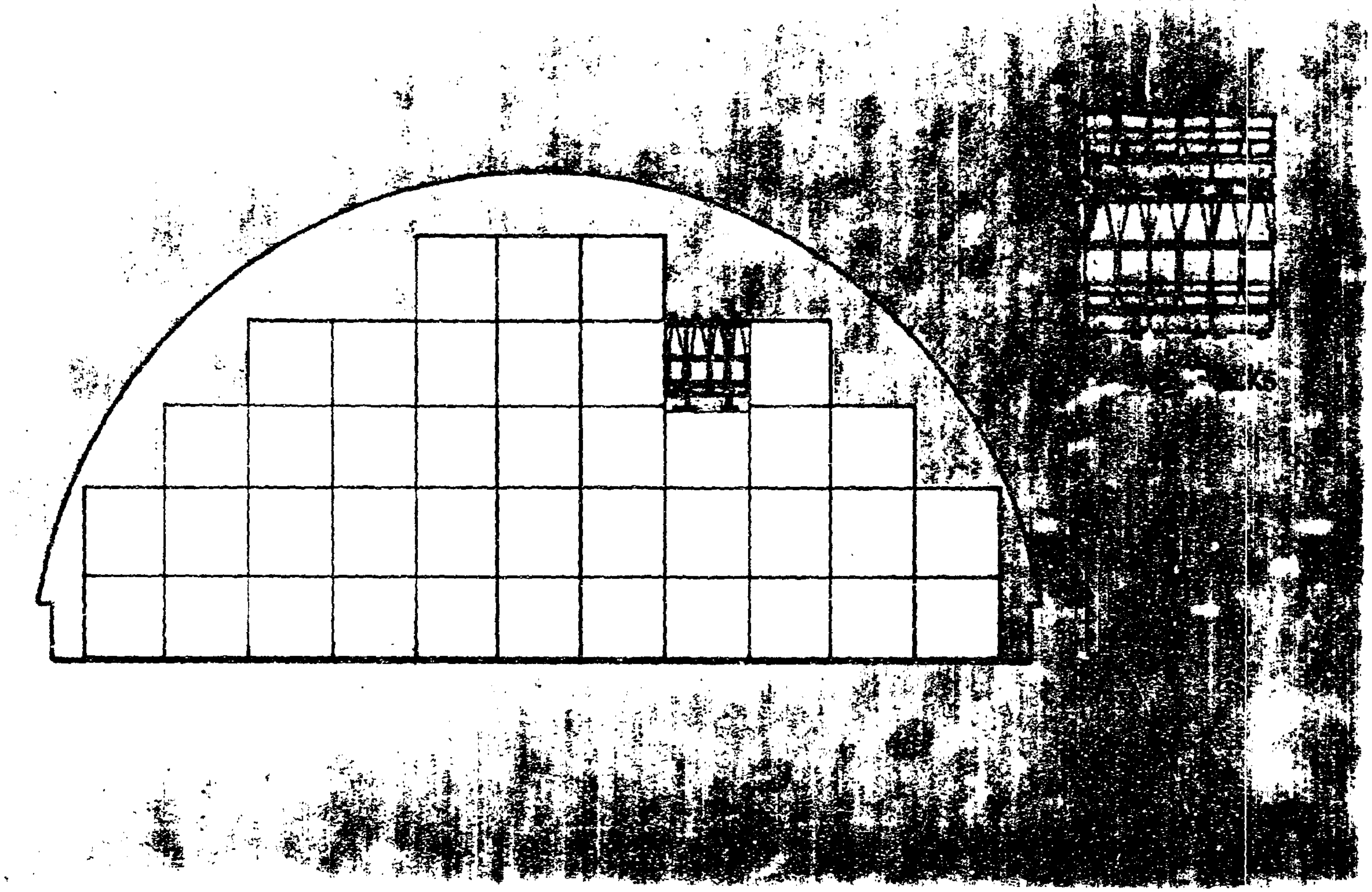
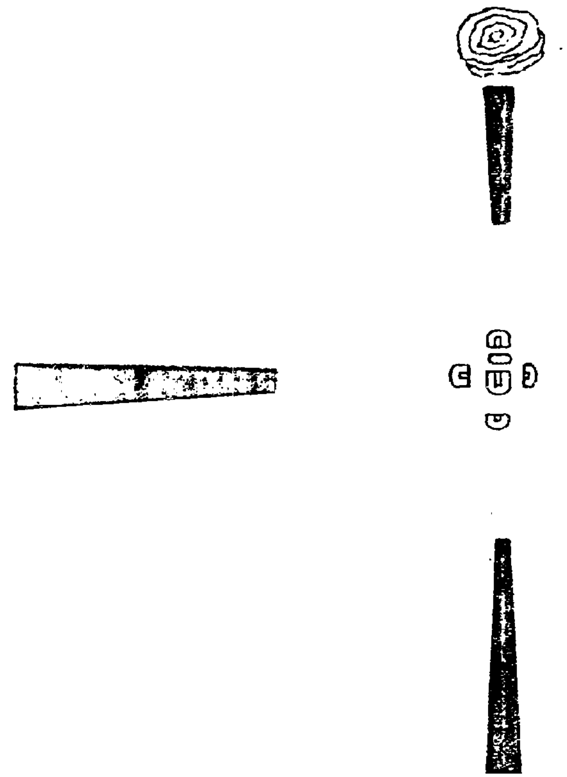


FIGURE VI

BLAST GAGE LOCATIONS



BRL Gage Distance (ft)	Expected Overpressure (psi)
410	20
2690	1

FIGURE VII

FRAGMENTATION COLLECTION AREAS

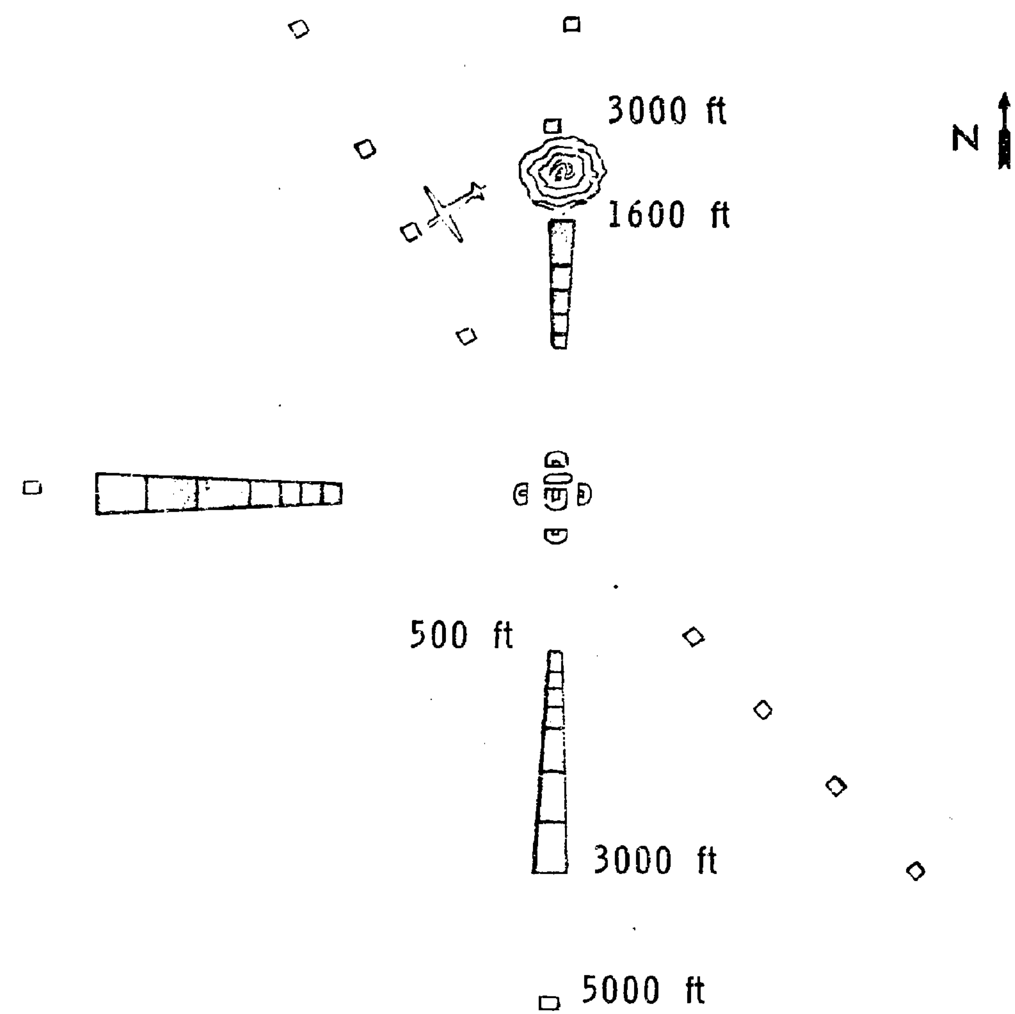


FIGURE VIII

Sensitivity of Explosive Weapons to Primary Fragment Impact An Experimental Investigation

by

D. S. Allan
Arthur D. Little, Inc.

ABSTRACT

A series of experiments were conducted as a preliminary step in the development of an experimental method for the determination of the relative sensitivity of explosive weapons to primary fragment impact. Right circular, cylindrical, steel projectiles, 1.5 inches in diameter, were impacted normal to the surface of bare and covered Comp B receiving charges and 155mm artillery shells loaded with Comp B. The results of the experiments were compared with that of previous investigators and the potential utility of this technique for determining relative sensitivity to primary fragment impact was evaluated. This work was carried out as part of a larger program on the development of a weapons sensitivity handbook[1] under the sponsorship of the Armed Services Explosives Safety Board.

INTRODUCTION

In many cases the mechanism by which an explosion may be propagated from one weapon to another during the manufacture, storage, and transport of explosive weapons involves fragment impact. This is particularly true in the manufacture of cased explosives where the unpackaged weapons may be located relatively close to each other as for example, on a conveyor. Under these conditions one is faced with the decision as to how far apart the weapons should be spaced to ensure that the fragments produced by the accidental explosion of one weapon will not impact with a nearby weapon in a way that it too will detonate.

It is our understanding that criteria for the required spacing of explosive weapons as given, for example, in the DOD Contractors' Manual[2] have been established by limited experiments involving the detonation of several actual weapons and by extrapolation of the results to other weapons.

PRECEDING PAGE BLANK

The determination of the safe spacing by tests where one weapon is detonated and the sympathetic detonation of surrounding weapons is observed can be expensive and the information so derived does not provide a very accurate means of predicting the minimum safe spacing for another similar but untested weapon. Improved methods of determining the minimum spacing as controlled by primary fragment impact are needed.

The principal objective of this program was to assess an approach to the establishment of conditions for the safe storage of explosive weapons when primary fragment impact is controlling. In this program we have reviewed previous work on the sensitivity of both cased and uncased explosives to primary fragment impact and have evaluated an experimental approach that offers potential as an improved basis for establishing safe storage conditions for preventing propagation of an explosion by primary fragment impact.

REVIEW OF PREVIOUS WORK

In this presentation our review of previous work is limited to a single study reported by Slade and Dewey(3) of the Ballistic Research Laboratories in 1957 since the experimental approach that we have employed evolved, at least in part, from the results of this work and because most of the other pertinent research is classified. For a more complete discussion of previous work on the sensitivity of explosives to fragment impact and on the correlation of the results of our experiments with the previous investigations the reader is referred to our final report to the Armed Services Explosives Safety Board(1). In the experiments reported by Slade and Dewey cylindrical projectiles were fired at both bare and "cased" tetryl and Composition B. The right circular cylinders were fired so that their longitudinal axes impacted other normal to the surface of the explosive or at some predetermined angle. A large number of tests were made where the velocity at which the cylinder initiated detonation (50 percent of the time) was determined as a function of the following variables:

- Weight of the cylindrical projectiles
- Diameter of the projectile's impacting surface
- Projectile material
- Angle of impact

- Thickness (and material) of a cover plate placed over the explosive
- Temperature of the receiving charge

The variation between weight of the cylindrical fragment and the diameter of its impacting surface was obtained by a combination of changes in the overall diameter of the cylinder, in the length of the cylinder, and by reducing the diameter of the forward section of the cylinder.

The most pertinent results of this study were as follows:

- In normal impacts against bare explosive the critical (50 percent) velocity was independent of the weight of the cylinderical projectiles.
- In normal impacts the critical velocity depended upon the diameter of the projectile at its impacting surface. For Comp B (and steel projectiles) the relationship between critical velocity and fragment diameter was reported as

$$V = 2136d^{-1/2}$$

where V = critical velocity, ft/sec
d = diameter of projectile at impact, inches.

- The critical velocity increased both with an increase in the thickness of the cover plate and in the angle of impact.

ADL EXPERIMENTS

The overall results of the Slade and Dewey study indicated that the important variables that determined the critical fragment velocity necessary for initiating detonation of a specific explosive are a critical dimension of the fragment, the casing thickness and the angle of impact. This suggests that once the quantitative relationship between these variables is established for a given explosive the sensitivity of all weapons containing this explosive to primary fragment impact may be predicted. Furthermore, since the characteristics (velocity, shape and direction) of fragments produced by most explosive weapons are either known or can be determined

quite readily the above relationship, once determined, might be employed to analytically predict the probability of the detonation of an explosive weapon propagating to another nearby weapon of like kind as a function of their spacing and relative orientation.

To further evaluate the potential of this method of determining sensitivity of explosives to fragment impact a series of experiments were conducted by ADL with cylindrical fragments 1.5 inches in diameter fired to impact normally with both bare and covered Comp B charges and 155mm artillery shells loaded with Comp B. The principal objectives of the experiments were to obtain data for large fragments (the largest fragment employed by Slade and Dewey was approximately 0.6 in. in diameter) and to establish a comparision between the sensitivity of an actual explosive weapon and a simple cylindrical explosive charge covered with a steel plate of the same thickness as the weapon's casing (simulated charge). It also was perceived that if the experiments indicated that there is a discrepancy between the sensitivity of the simple or simulated charge and that of the actual shell the method would still have utility as a means of determining the <u>relative</u> sensitivity of explosive weapons.

The simulated cylindrical fragments weighing approximately 400 grams are shown in Figure 1. The simulated receiving charge and the arrangement employed in the experiments are presented in Figures 2 through 4. A total of ten firings were made at bare Comp B charges, eight firings at cylindrical Comp B charges covered with a 9/16 in. thick mild steel plate and twelve firings at the 155mm artillery shells at a point where the casing thickness was also 9/16 inches thick. The experiments were performed at the Space Research Corporation in North Troy, Vermont.

The results of these experiments are summarized in Figure 5. The results of the bare charge experiments are correlated with the Slade and Dewey data as shown. It was found that the critical velocity for the 1.5 inch projectile was much lower than the previous relationship ($V = 2136d^{-1/2}$) would have predicted. In the experiments with both the covered Comp B and the 155mm shells there was a well defined difference in critical velocity between that necessary to produce a partial detonation and that for complete detonation. The critical velocity for complete detonation was essentially the same for the simulated and actual cased charges. The critical velocity

at which partial detonation occurred was apparently not the same for the two types of changes. However, since only one test was made in which no reaction occurred with the simulated charge additional experiments are needed to either confirm or deny this discrepancy.

The conclusions drawn from this preliminary work are as follows:

- The critical velocity for large fragments can be much lower than extrapolation of data acquired from tests with small fragments might indicate.
- The effect of casing thickness on critical velocity appears to be much less pronounced for large fragments.
- The method of simulating actual explosive weapons by using simple covered cylindrical charges for determining fragment impact sensitivity was not confirmed and needs further evaluation.
- The employment of fragment impact tests with actual explosive weapons to provide a measure of their relative sensitivity may require tests with both large and small fragments.

REFERENCES

1. Allan, D. S. and Meyers, S., "Development of a Weapons' Sensitivity Handbook," (U) Final Report (Phases I and II), Contract No. DAH-C04-70-C0042.

2. "DOD Contractors' Safety Manual for Ammunition, Explosives, and Related Dangerous Material," DOD 4145.26M, Department of Defense Office Asst. Secretary of Defense (Installations and Logistics), October 1968, p. 14-13.

3. Slade, D. C. and Dewey, J., "High Order Initiation of Two Military Explosives by Projectile Impact, BRL Report No. 1021, Ballistic Research Laboratories, July 1957.

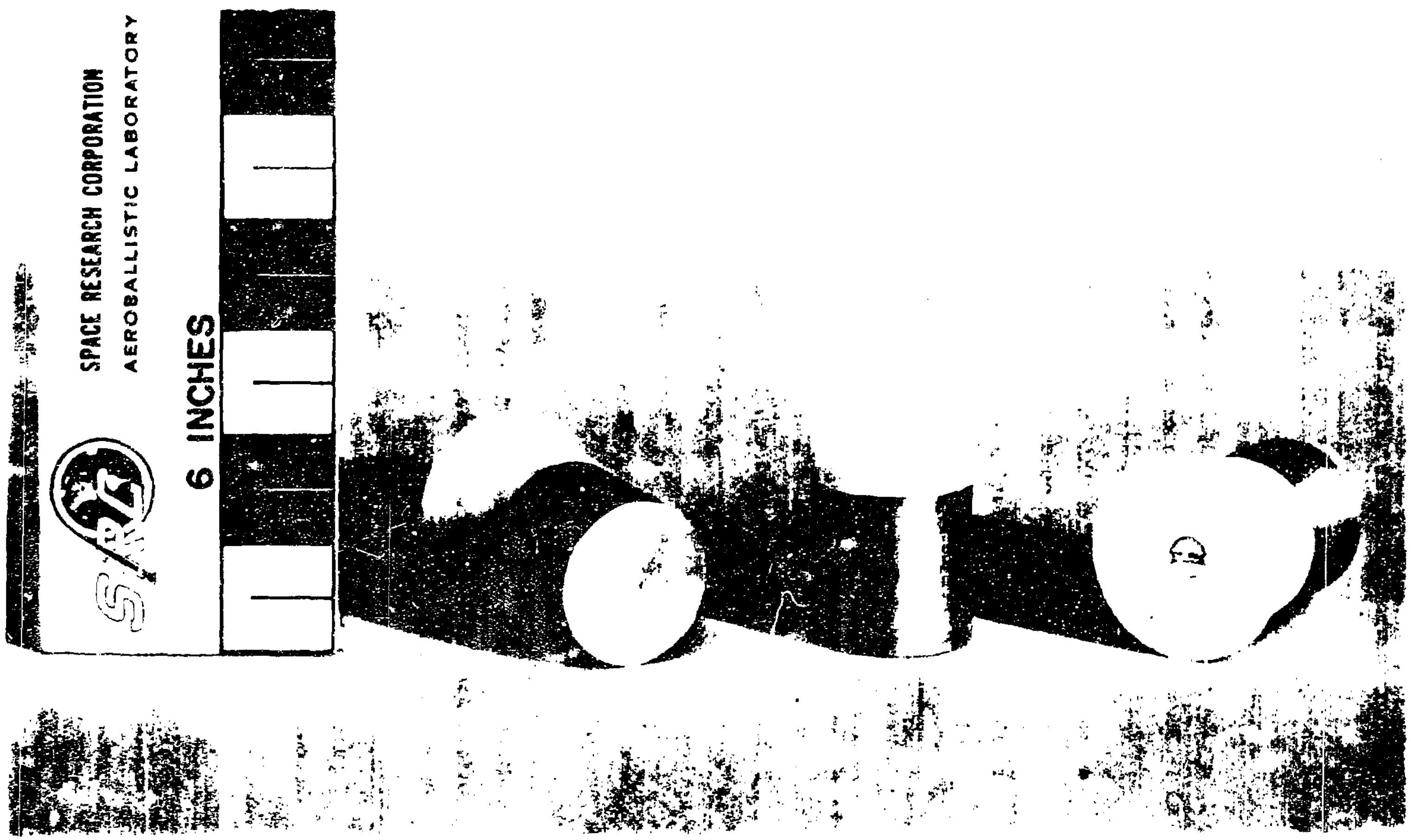


FIGURE 1 SIMULATED FRAGMENT - 1.5" DIAMETER

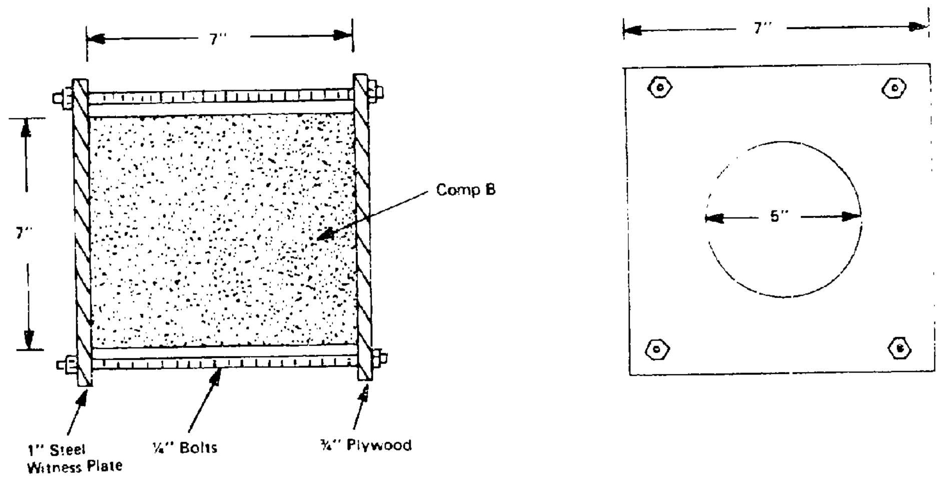


FIGURE 2 CONFIGURATION OF RECEIVING CHARGE BARE COMP B

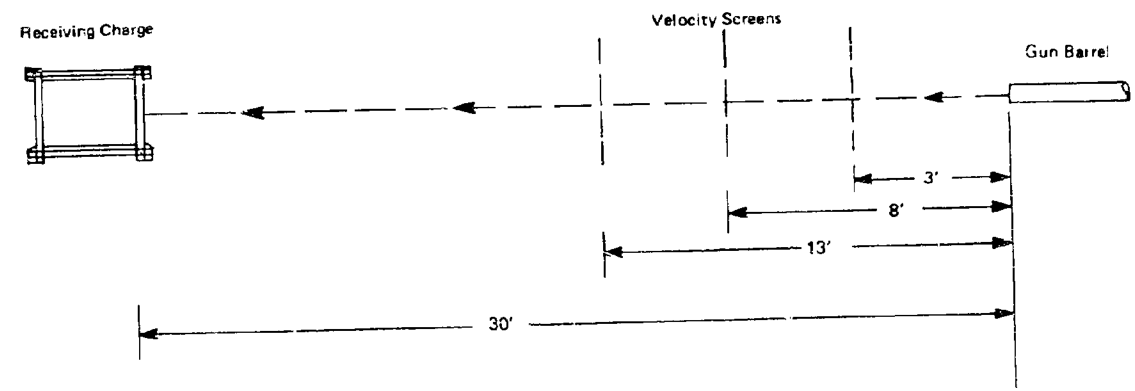


FIGURE 3 TEST ARRANGEMENT BARE COMP B AND SIMULATED SHELL TESTS

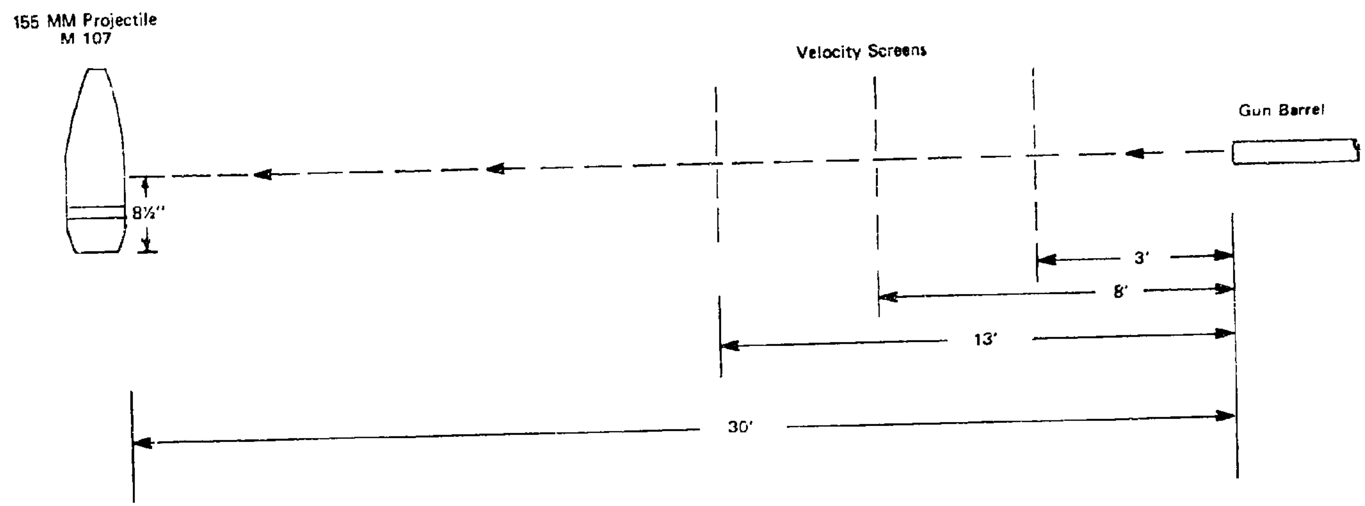


FIGURE 4 TEST ARRANGEMENT 155 MM PROJECTILE TESTS

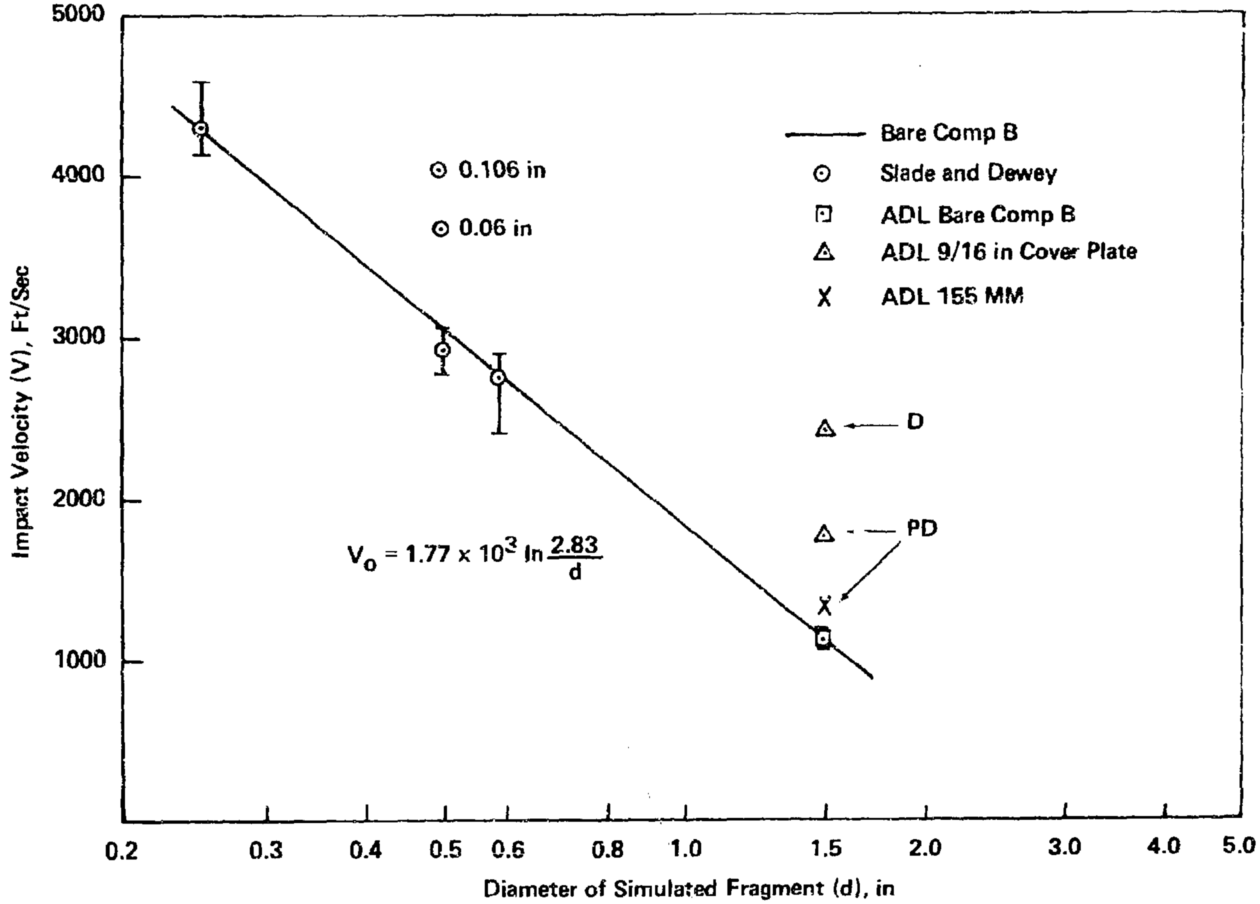


FIGURE 5 HIGH VELOCITY FRAGMENT IMPACT DATA

FRAGMENTATION HAZARDS TO UNPROTECTED PERSONNEL

by

D. I. Feinstein
and
H. H. Nagaoka

INTRODUCTION

The Armed Services Explosive Safety Board (ASESB) has recently defined a set of preliminary criteria for personnel protection against fragments originating from accidental explosions. These criteria are:

- A hazardous fragment is a fragment having a kinetic energy at impact of 58 ft-lb or greater.

- An acceptable density of hazardous fragments is not more than one in 600 sq ft.

Recognizing that these or other criteria must be applied to determine minimum separation distances between various munition types and personnel, there is a need to generate the basic data characterizing the hazardous nature of these munitions. This data includes the fragment density at any point from an accidental detonation and the resulting probability of injury to personnel within the hazardous area. This paper reviews the Fragment Hazard Model, the use of munition effectiveness data as input to that model, and the sensitivity of the above criteria to actual munition effectiveness data.

Under Contract No. DAHC-04-69-C-0056 with the U. S. Army Research Office-Durham, IIT Research Institute (IITRI) has been conducting a series of investigations concerning fragment hazards associated with accidental detonation of munitions. This work has been performed under the direction of the ASESB.

During Phase I and II of this Fragment Hazard Study a computational model was developed for determining the probability of injury or damage by fragments from a single munition round to a variety of targets including a person standing in the open. In order to determine these probabilities the model predicts the number density in the ground plane of all fragments. These fragments are then screened as to being hazardous to selected targets using a criteria of critical mass and velocity.

The objective of the current program is to generate the information necessary to establish the minimum separation distance to personnel using existing data and techniques with minor modifications.

Review of Fragment Hazard Model

The mathematical model for computing fragment density and damage probability contours for various munition/target combinations on a probability basis was formulated and programmed for electronic data processing. The mathemtical model (refer to Fig. 1) is limited to the consideration of the single munition without environmental protection. The model is modular and accepts as inputs:

- The spatial distribution of fragment masses and velocities for individual munitions, which are defined for each 5 deg interval of polar angle.
- The k-factors for the individual munitions, which express the relationship between fragment masses and projected areas for various munition types.
- Vulnerability criteria for targets of interest, in the form of mass-velocity relationships of impacting fragments.

Outputs of the model include:

- Fragment density contours showing distances to isodensity lines for all azimuths. Contours can be printed for all fragments or for various classes of fragments.
- Injury/damage probability contours, showing ground distances to isoprobability curves at all azimuths for various munition/target combinations.

Large quantities of terminal ballistic property data are used in developing these outputs. These data are generated by numerical methods from the equations of motion for the fragments. Since these computations represent the bulk of the computational burden involved in exercising the model, a terminal ballistic data file has been developed which covers the range of fragment masses, initial velocities, initial elevation angles, and k-factors encountered in exercising the model. Terminal ballistic properties for trajectories whose initial conditions are common to many polar angles and munition types are computed only once, stored in a computer data file, and retrieved as needed for solving specific hazards problems. Elements of this model include the following:

Fragment and Drag Parameters

A series of twenty classes of fragment masses, eight velocity classes, and two k-factors were selected for generation

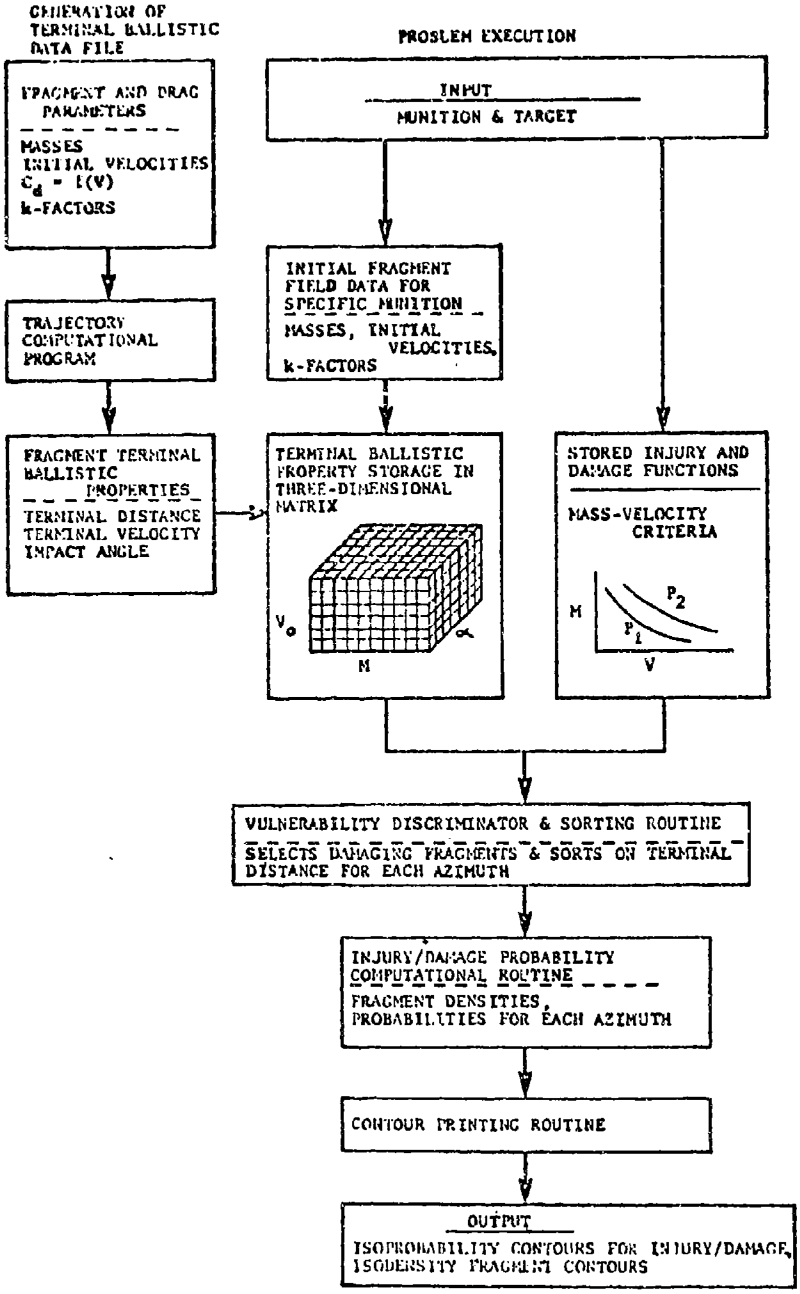


Fig. 1 FLOW CHART PHASE II FRAGMENT HAZARD MODEL

of the file of terminal ballistic data. These parameters cover the range of values encountered in the seven munitions selected.

Trajectory Computational Routine

This routine is used to compute the requisite terminal ballistic properties of individual fragments--terminal distance, terminal velocity, and impact angle. Formulation of the trajectory equations includes consideration of the drag coefficient as a function of fragment velocity.

Terminal Ballistic Data File

Terminal ballistic data for fragments are stored in a computer file in a manner which can be likened to a three-directional matrix as shown in Figure 1. Terminal properties of a fragment are retrieved for individual problem execution from cells corresponding to the actual masses (M), initial velocities (V_o) and initial elevation angles (α_o). As set up, the model uses linear interpolation among the parameters M, V_o and α_o wherever fragment parameters for the individual munition differ from those used in generating the terminal ballistic data file.

Stored Injury and Damage Functions

Injury and damage functions define mass-velocity relationships for various probabilities of damage or injury.

Vulnerable Fragment Discriminator and Sorting Routine

This routine selects terminal ballistic properties of fragments whose mass-velocity relationships are above injury or damage levels and sorts them according to terminal distance. This is done successively at 5 deg intervals of azimuth.

Injury/Damage Probability Computational Routine

Fragment densities and injury/damage probabilities are computed in this routine, bringing target area into consideration. This routine is also exercised successively for azimuths at 5 deg intervals.

Contour Printing Routine

This routine prints contours of equal fragment density and equal injury/damage probability for the various combinations of munition and target.

Use of Munition Effectiveness Data

Previous studies have indicated that published munitions effectiveness data, as they now stand, are not suited to far field fragment hazard analysis. In general, these data place the heavier fragments into one or two broad weight intervals with a corresponding average weight. Since those heavier fragments travel greater distances and have the most damaging terminal effects, it is necessary that they be divided into an adequate number of weight intervals.

During this study four subtasks have been accomplished concerning the revision of the near-field fragment mass distribution.

- Fragment distribution characteristics were assessed from existing munitions effectiveness data,
- Aberdeen Proving Ground was visited to document, original data from arena test firing records,
- Fragment ballistics sensitivity curves were plotted from the IITRI ballistic data file, and
- Damaging fragment energy criteria were assessed.

In the subsequent paragraphs, the significant results obtained from these subtasks will be summarized.

Published Fragment Distribution Characteristics

In preparation for the Aberdeen Proving Ground (APG) trip, the fragment mass distribution characteristics were assessed from existing munitions effectiveness data. Percent total fragment weight ($\%/W_T$) versus fragment weight group (M) curves were plotted for the APG data munitions (i.e., 105 mm, 155 mm, 175 mm shells and the 750 lb bomb). In addition, the percent number of fragments (% N) greater than 150 grains versus fragment weight group (M) curves were plotted on the same graph. These data shown in Figs. 2-8 may be summarized as follows for $M > 150$ grains:

Munition	$\% W_T$	$\% N_T$	N	N_A
105 mm	52	5.9	315	32
155 mm	70	13.5	943	94
175 mm	78	12.6	1364	136
750 lb	86	15.1	3650	365

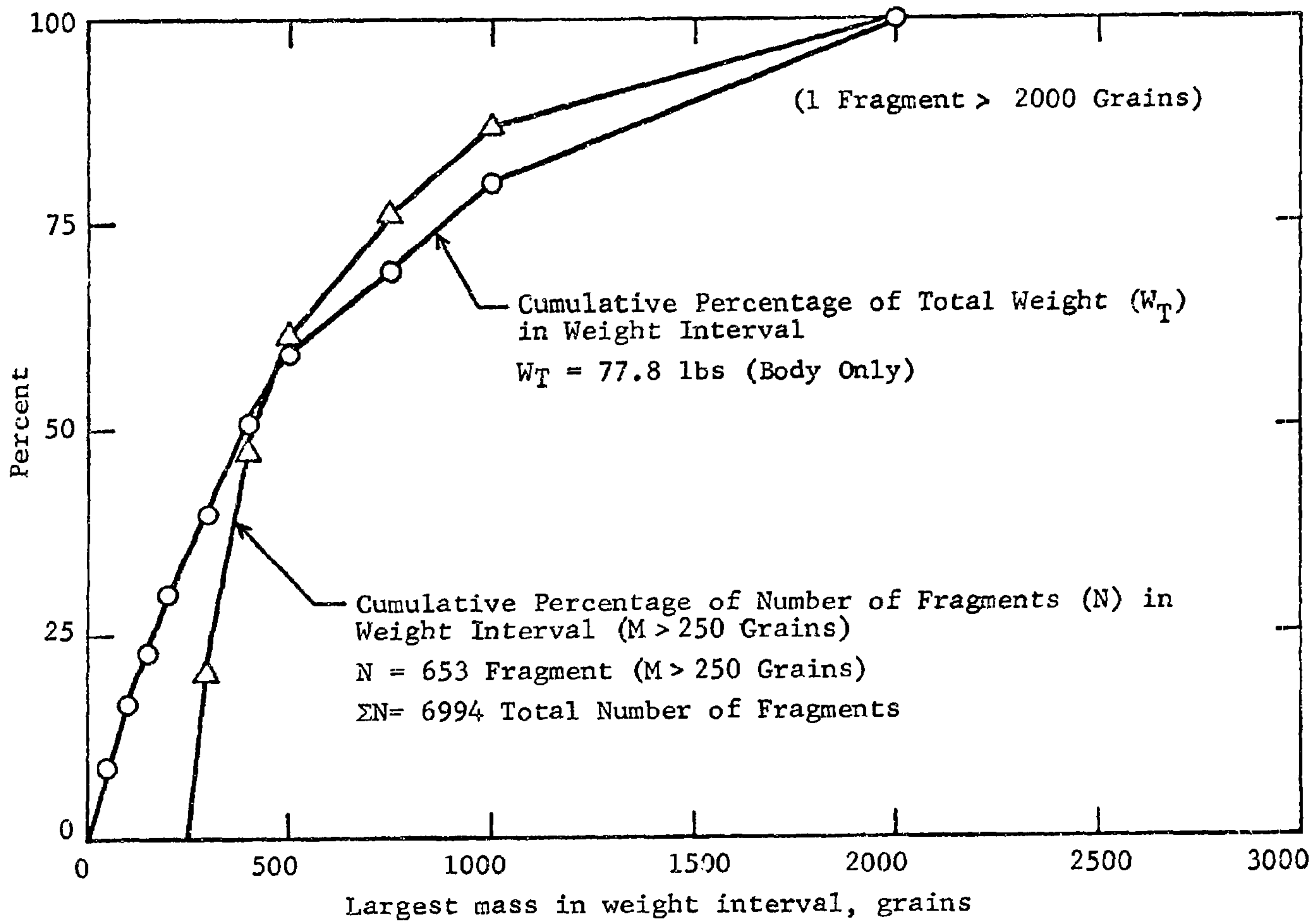


Fig. 2 FRAGMENT DISTRIBUTION DATA - 155 MM SHELL M107 (COMP B LOADED)

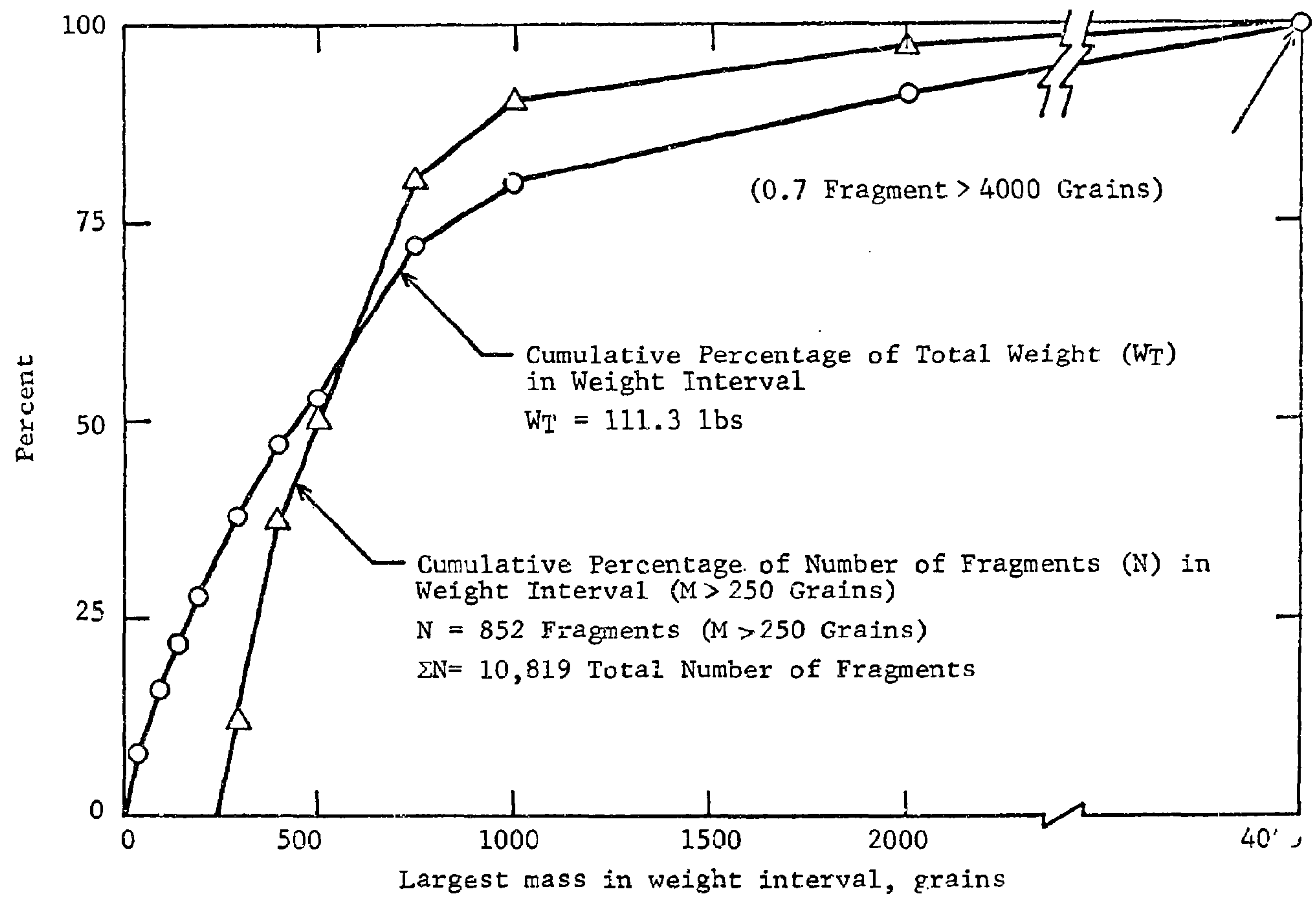


Fig. 3 FRAGMENT DISTRIBUTION DATA - 175 MM SHELL M437A2 (COMP B LOADED)

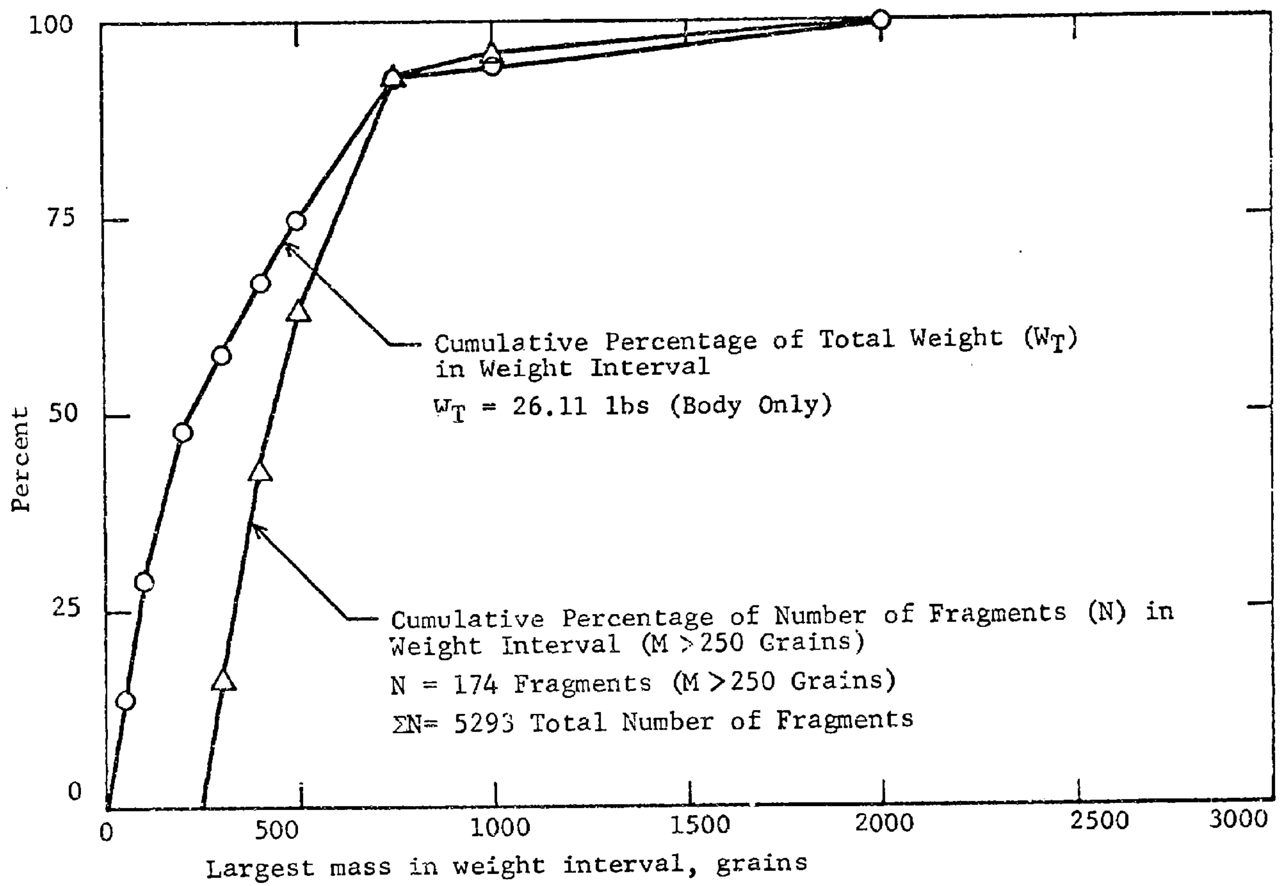


Fig. 4 FRAGMENT DISTRIBUTION DATA - 105 MM SHELL M 1 (COMP B LOADE")

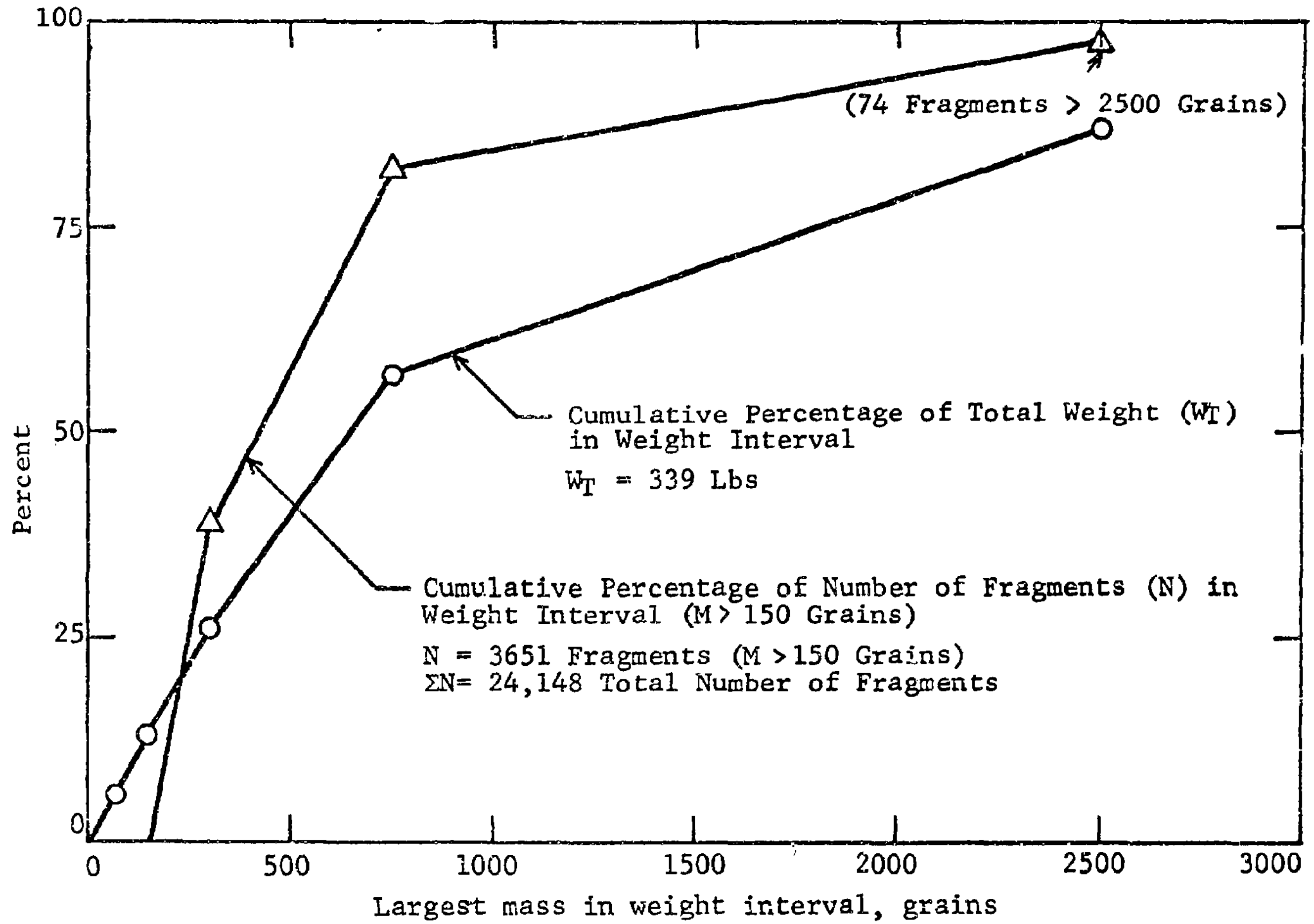


Fig. 5 *FRAGMENT DISTRIBUTION DATA - 750 LB BOMB M117A2* (TRITONAL LOADED)

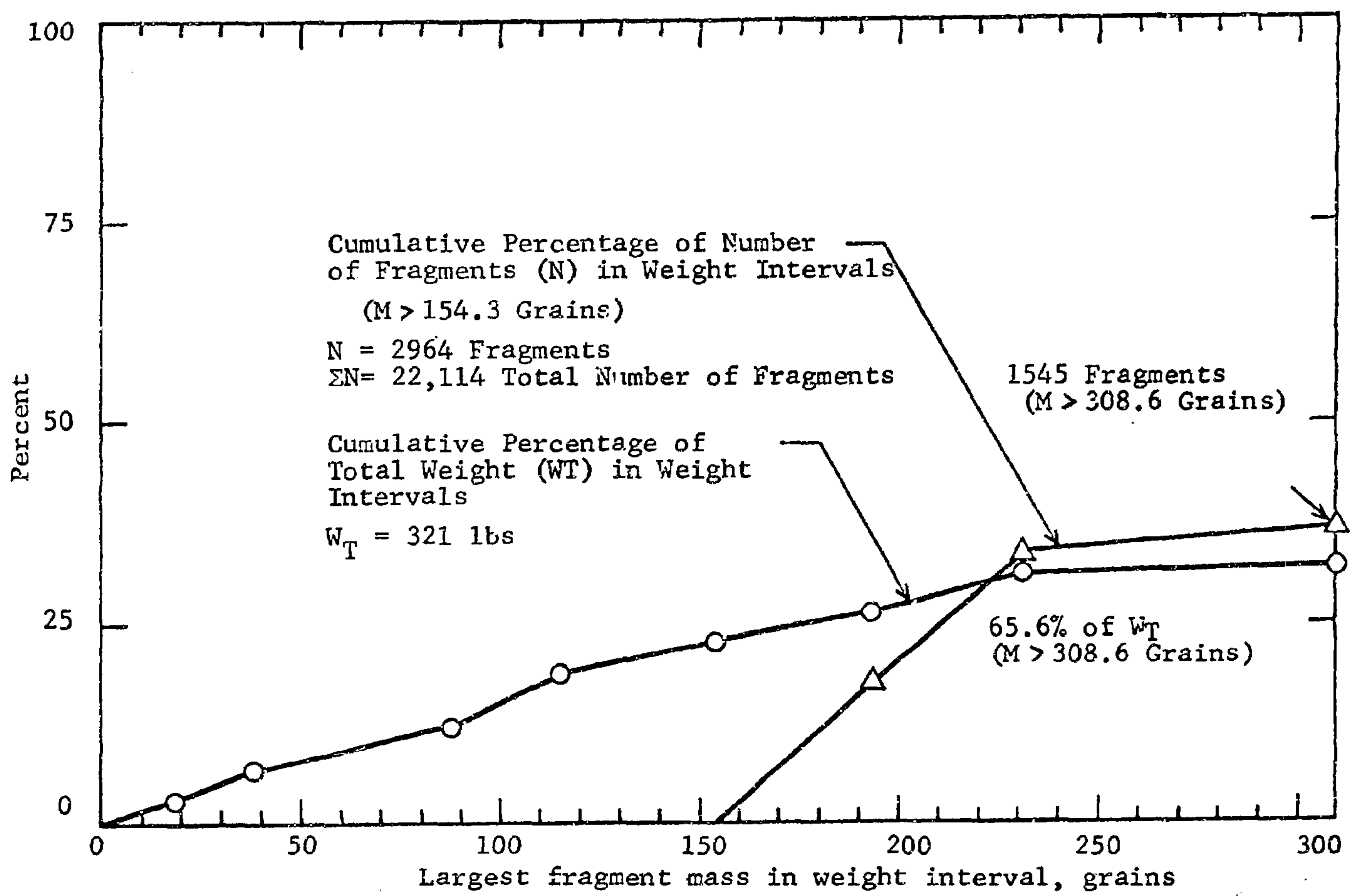


Fig. 6 FRAGMENT DISTRIBUTION DATA - 500 LB LOW DRAG BOMB, MARK 82 MOD 1 (H-6 LOADED)

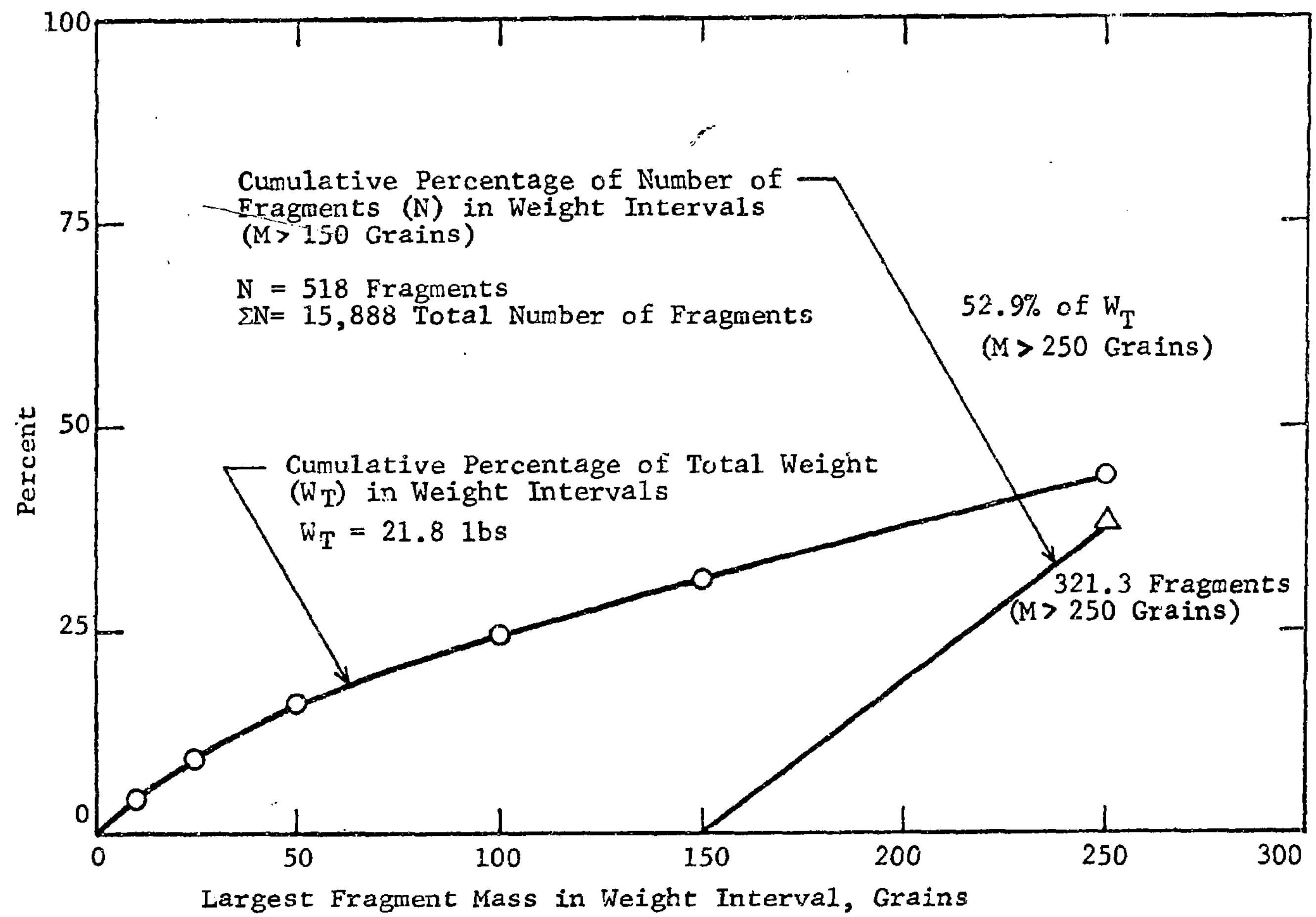


Fig. 7 FRAGMENT DISTRIBUTION DATA - 5IN./38 PROJECTILE MARK 49 MOD 0 (UT) (CCMP A-3 LOADED)

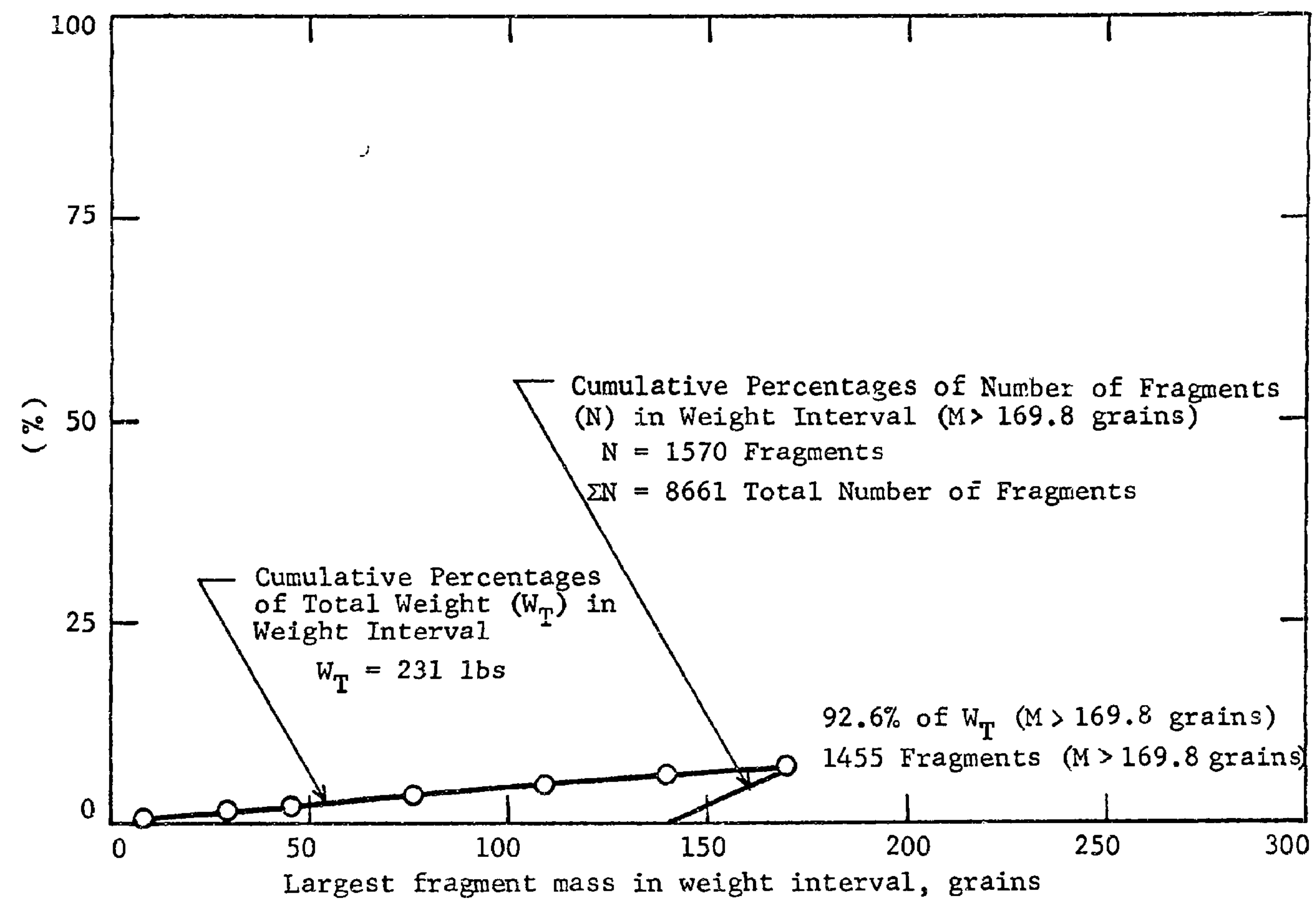


Fig. 8 FRAGMENT DISTRIBUTION DATA - 8 IN./55 PROJECTILE MARK 25 MOD 1 (HC) (EXPLOSIVE D LOADED)

where $\% W_T$ = percent of total fragment weight ($M > 150$ grains)

$\% N_T$ = percent of total fragment number ($M > 150$ grains)

N = number of fragments ($M > 150$ grains)

N_A = estimated number of fragments reserved in arena (based upon 10% coverage by arena)

These important points may be noted from the table.

- Fragments greater than 150 grains represent 52 to 86% of the total weight.
- Fragments greater than 150 grains represent 6 to 15% of the total number of fragment.
- Fragments greater than 150 grains which are expected to be individually documented are relatively small in number.

These data were used to provide a frame of reference for the documentation of original arena test data at APG.

Documentation of Arena Data at APG

In collaboration with the Ballistics Research Laboratory, the arena test procedure and data analysis techniques used to obtain munition effectiveness data were reviewed. Arrangements were made to examine the original arena test firing records at the APG Technical Library for the following munitions:

- 105 mm Howitzer Shell M1
- 155 mm Howitzer Shell M107
- 175 mm Gun Shell 437A2
- 750 lb Bomb M117

For each munition the following information was documented.

- Test munition physical measurements,
- Specifications for arena test facility,
- Listing of mass groups and polar zones,
- Individual listing of fragment weights greater than 150 grains.

From among these data, sufficient information was recorded to revise the mass distribution groups from original arena test records.

In addition, contacts were established at the U. S. Naval Weapons Laboratory (NWL) to obtain similar arena test data for the following munitions.

- 500 lb Low Drag Bomb Mark 82 Mod 1 (H-6 Load)
- 5-in/38 Projectile Mark 49 (CCMP A-3 Load)
- 8-in/55 Projectile Mark 25 (Explosive D Load)

These data will be procured in the near future.

<u>Fragment Ballistics Sensitivity Study</u>

A fragment ballistics sensitivity study was made using the IITRI Ballistic data file. This study provided input information regarding the revision of mass groups. For fragment hazard analysis, the key terminal ballistics parameters are as follows:

- V_T - Terminal velocity of fragment impact
- R - Range of fragment impact.

The sensitivity of these far-field parameters were examined in relation to changes in the following near-field fragment parameters.

- V_o - Initial velocity of fragment
- α_o - Initial elevation angle of fragment
- M - Mass of fragment
- k - Fragment shape [illegible].

Parametric curves were plotted to illustrate the relationships for potential damaging fragments from the munitions being evaluated and are shown in Figs. 9 through 14.

Some of the more significant relationships may be summarized as follows:

- Initial fragment velocity (V_o) has relatively small effect on the terminal velocity (V_T) for fragment elevations greater than 2.5°, but does influence the fragment range (R),
- Initial fragment elevation (α) greater than 2.5° has little effect on the terminal velocity (V_T), but does influence the fragment range (R). Maximum range occurs at about 22.5°.
- For initial fragment elevation (α) below 2.5°, significant changes occur in both terminal velocity (V_T) and range (R).

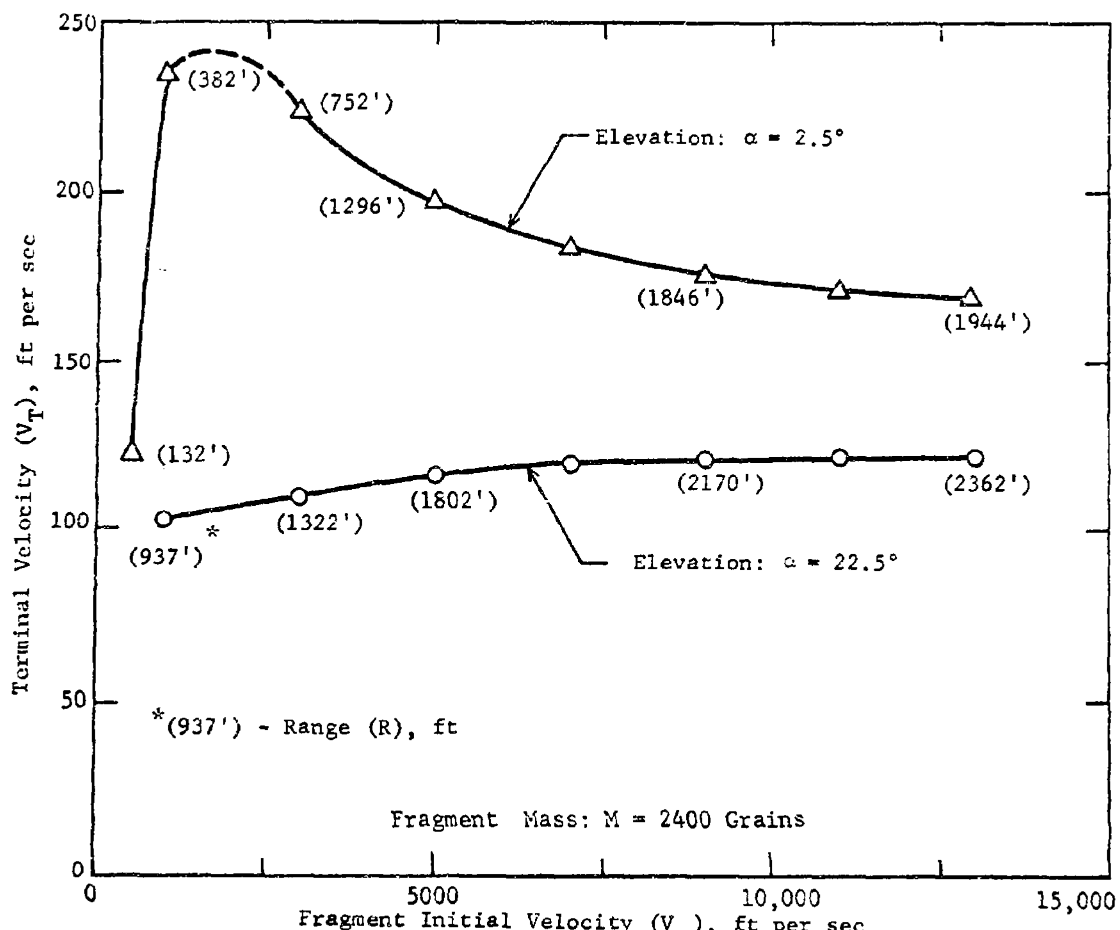


Fig. 9 *INITIAL VELOCITY (V_o) VS TERMINAL VELOCITY (V_T)*

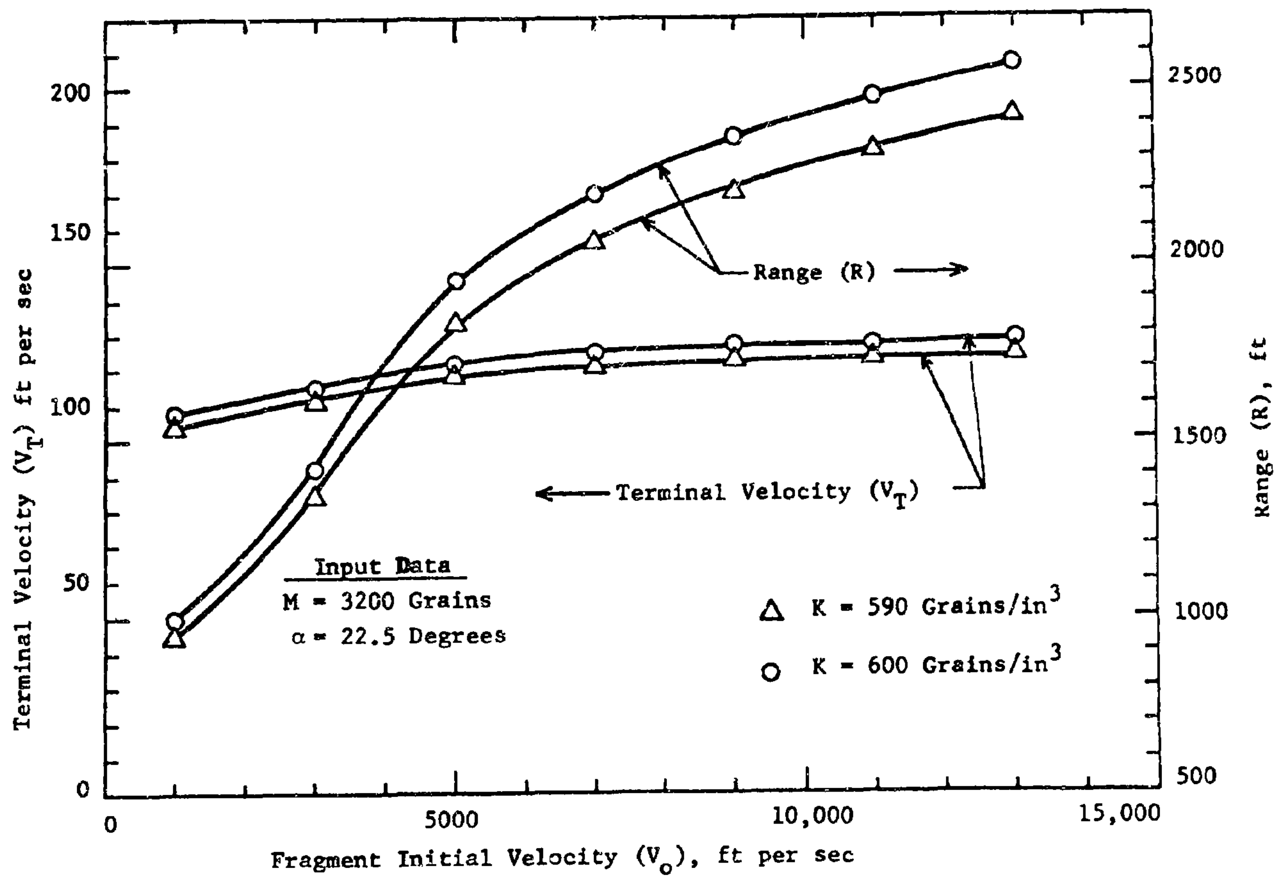


FIG. 10 EFFECT OF FRAGMENT SHAPE FACTOR (K) ON TERMINAL VELOCITY (V_T) AND RANGE (R)

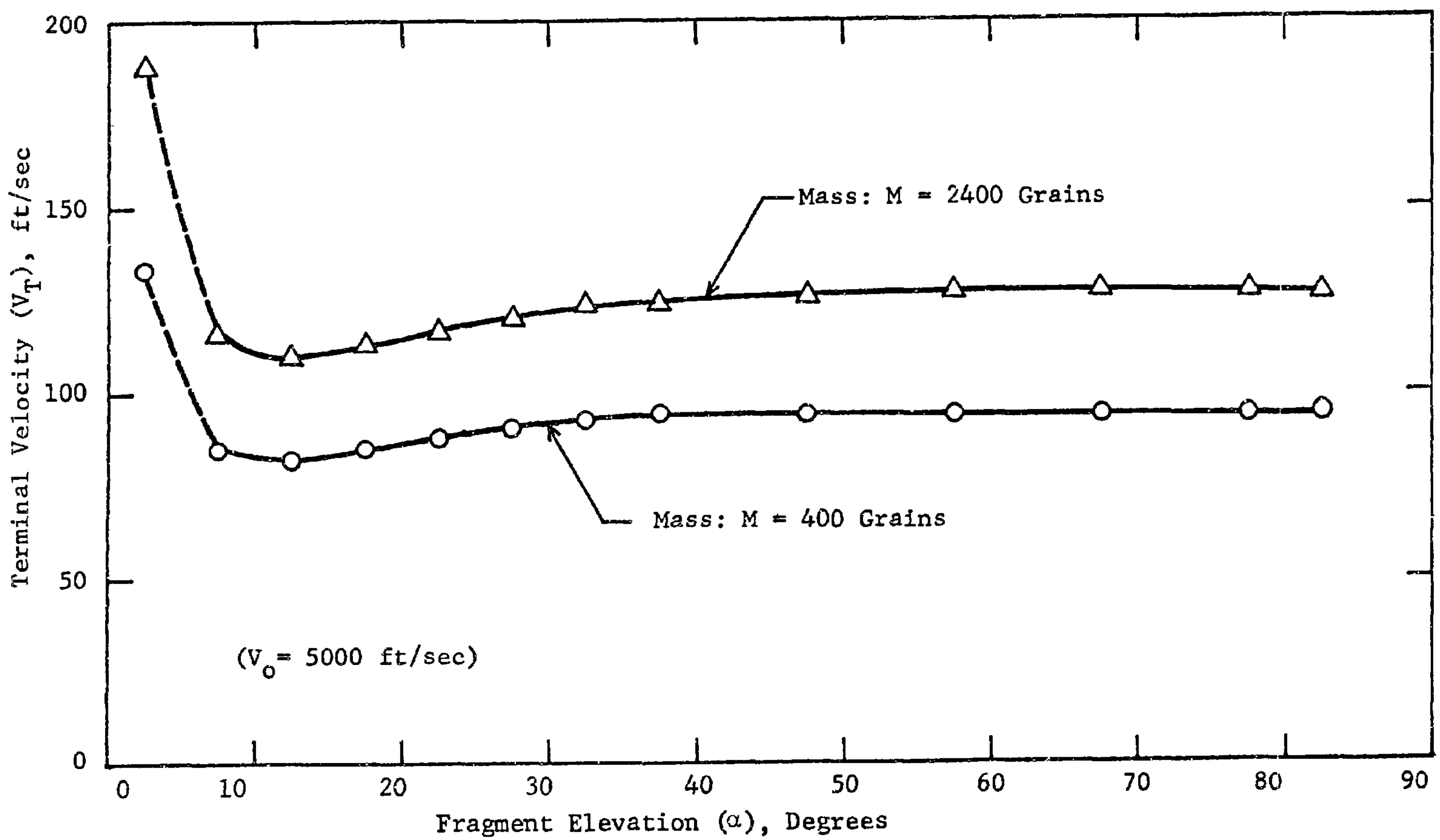


Fig 11 ELEVATION (α) VS TERMINAL VELOCITY (V_T)

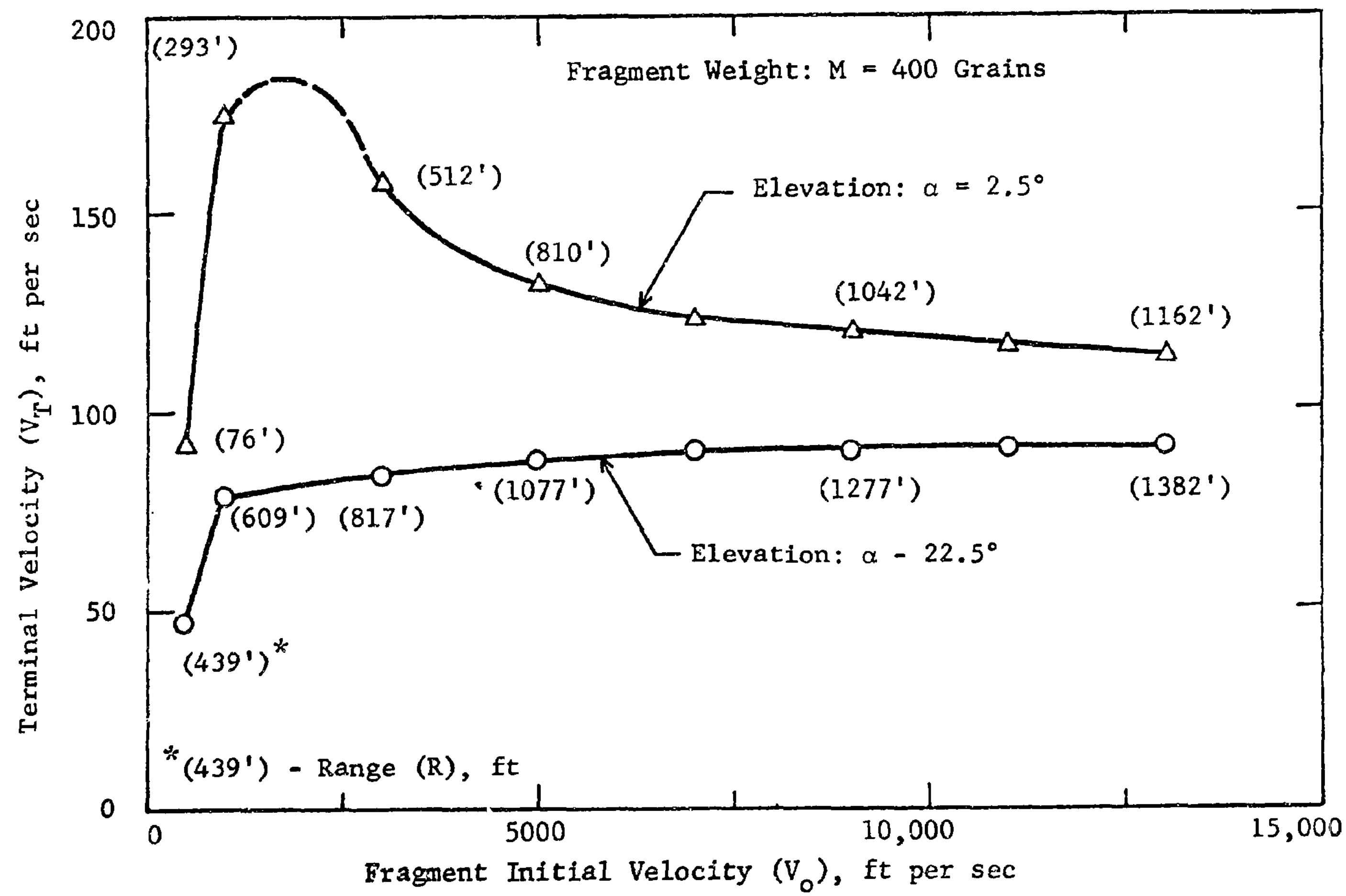


Fig. 12 FRAGMENT INITIAL VELOCITY (V_o) VS TERMINAL VELOCITY (V_T)

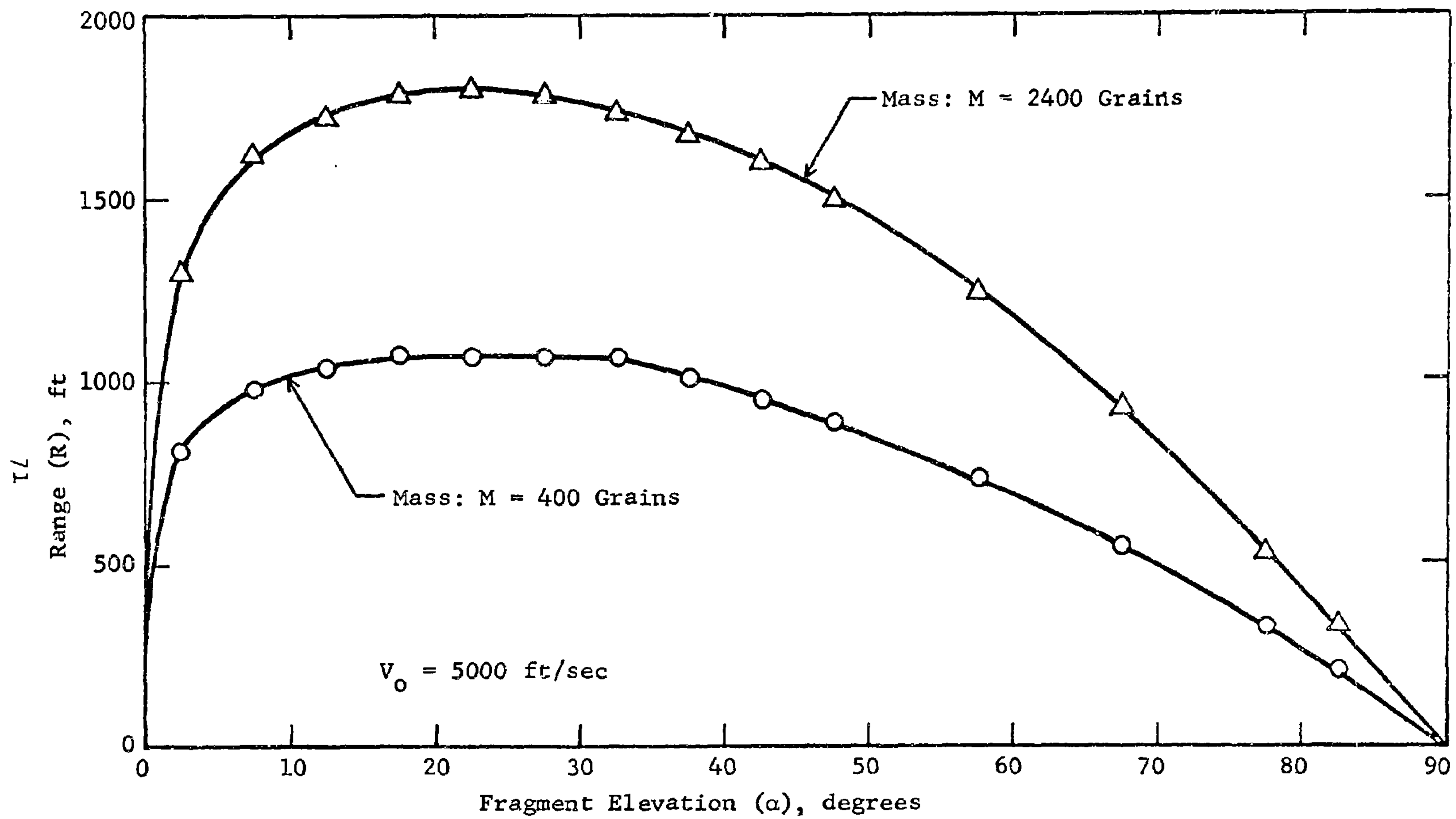


Fig. 13 ELEVATION (α) VS RANGE (R)

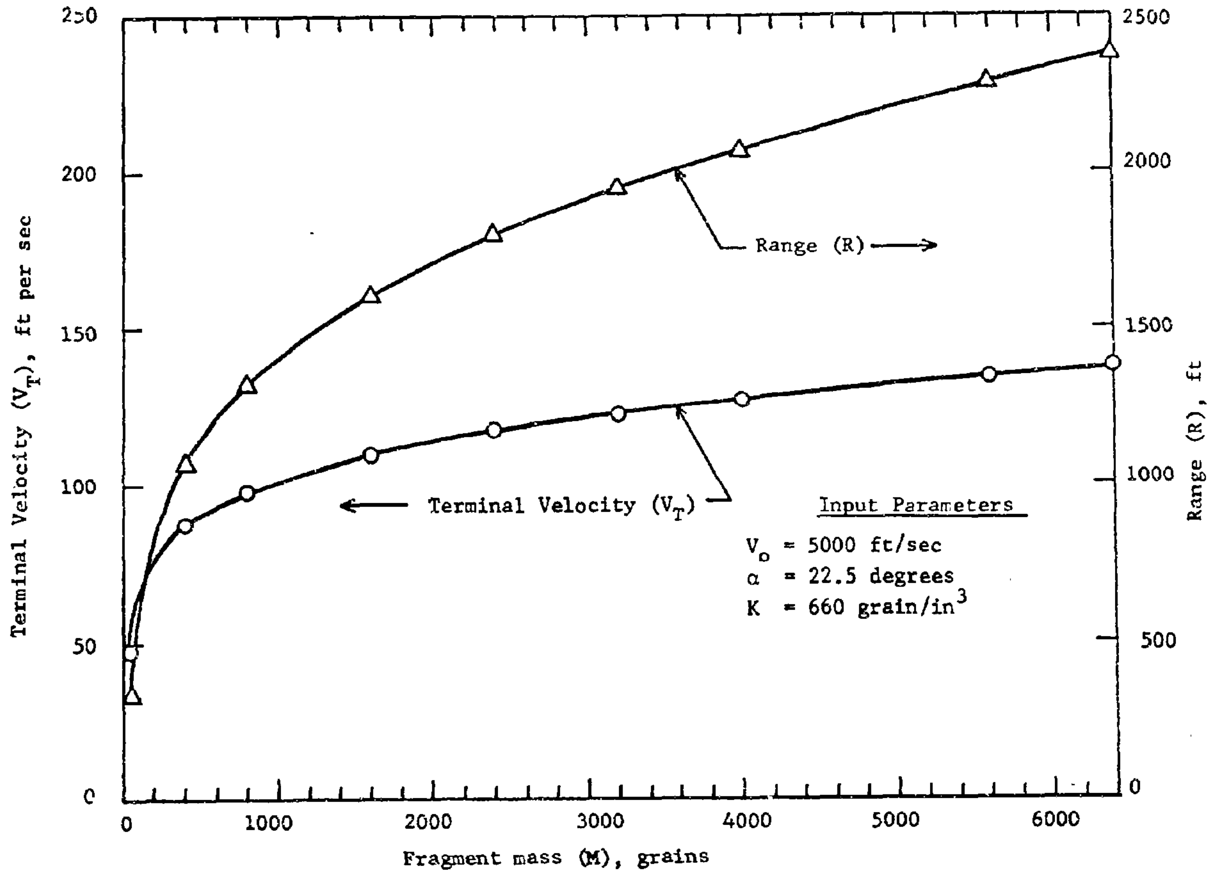


Fig. 14 FRAGMENT MASS (M) VS TERMINAL VELOCITY (V_T)

- For fragment masses (M) from 400 to 3200 grains, with V_o = 5,000 fps, and α = 22.5°, only moderate changes occur in terminal velocity (V_T) from 85 to 120 fps, but the range (R) changes from 1009 to 1835 ft. Similar relationships hold at α = 2.5°, except V_T is about 50% higher.

- For changes in fragment shape factors (k) from 590 to 660 gr/in^3, relatively small changes occur in V_T and R.

Damaging Fragment Energy Criteria

The damaging fragment energy criteria were plotted in terms of fragment mass (M) versus terminal velocity (V_T) curves from the following sources.

- New ASESB 58 ft-lb criterion
- Previous IITRI personnel injury criterion

From these curves, Fig. 15, it was found that the previous IITRI criterion represents a damaging fragment energy value of about 10 ft-lbs as compared with 58 ft-lbs for the new ASESB criterion.

Data from the fragment ballistics sensitivity study were used to estimate the minimum damaging fragment weight. These data are summarized below.

Energy Criterion	Minimum Damaging Fragment Weight (Grains) α = 22.5°	α = 2.5°
58 ft-lb	2,000	1000
IITRI Data	600	300

The implications of these estimated minimum damaging fragment weights were examined in the context of the published munitions effectiveness data. The important findings related to the 58 ft-lb criterion are summarized below.

- The number of fragments greater than 2,000 grains are as follows: 105 mm - 0, 155 mm - 1, 175 mm - 20, 750 lb bomb - 88 fragments (APG munitions data).

- The above data indicates that only the 175 mm and 750 lb bomb may have a sufficient number of damaging fragments to constitute a hazard for initial fragment elevations greater than 2.5 degrees.

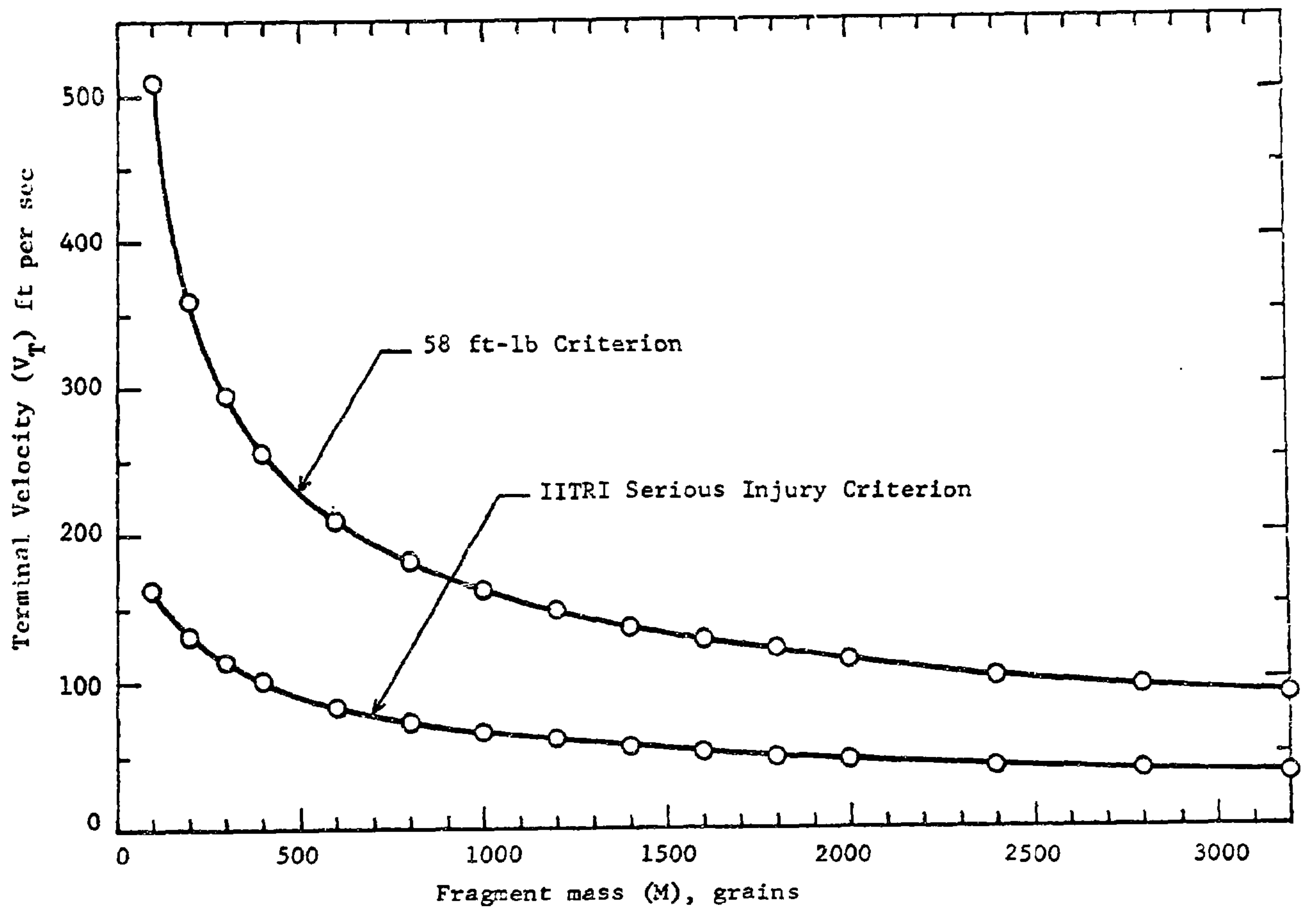


Fig. 15 DAMAGING FRAGMENT ENERGY CRITERIA

- If the fragment density criterion of one impact for each 600 ft^2 is superimposed on the energy criterion, the hazard probably will be markedly attenuated.

- The numb r of fragments between 1,000 and 2,000 grains ' e as follows: 105 mm - 6, 155 mm - 83, 175 mm - 71, 750 lb bomb - 569 fragments (APG munitions data).

- The above fragments are damaging if projected at an initial elevation angle below 2.5 degrees.

- Since low elevation angle fragment characteristics are based upon a single initial elevation angle of 2.5 degrees, further studies should be conducted to refine these data.

Summary

From the sensitivity analysis of fragment trajectory parameters, which was conducted above, it is apparent that the vulnerability criteria, when coupled with actual munition data, will lead to nonconservative estimates of personnel vulnerability. In addition, it has been shown that the fragments originating with low elevation angles result in the most hazardous terminal effects.

It is felt that the current effort will result in either a more conservative personnel vulnerability criteria and/or a new trajectory computation technique being integrated into the IITRI code to more accurately account for low elevation fragments.

SEQUENTIAL EXPLOSION STUDIES

J. J. Swatosh Jr.
Research Engineer
IIT Research Institute
10 W. 35th Street
Chicago, Illinois 60616

ABSTRACT

An experimental program conducted for the Armed Services Explosives Safety Board to determine blast pressures, peak impulse, and catchup times of shock waves generated by sequentially detonating two explosive charges. The parameters varied in this experimental series included charge spacing, time delay between detonations, and orientation of the charges with respect to two right angle blast lines. This presentation includes a brief description of the experimental setup and a preliminary look at some of the data obtained. Particular emphasis will be placed on pressure-distance and time-distance contours around the sequential detonations.

PRECEDING PAGE BLANK

1. INTRODUCTION

A series of 60 experiments was designed to investigate the effects of detonation time delay, charge separation, and orientation between two sequentially detonated charges. This paper summarizes this effort, as completed to date, being conducted by IIT Research Institute for the Armed Services Explosive Safety Board under Contract DAHC-04-71-C-0026.

Previous work[1] in this area indicated that there is a strong directional effect on the coalescence of successive blast pulses from sequentially detonated charges. It was clear that there is a wide possible variation of the locus of coalescence for two equal charges at a given time delay, and hence a wide variation of safe distance, as a function of orientation.

As a result of the previous work on sequential explosions, and because it did not adequately cover the variation of all the control parameters, this current program has been undertaken. The 60 experiments conducted for this program represent a full factorial experiment plan for the following control variable values.

Time delay, msec:	2.2, 2.9, 3.6, 4.3, 5.0
Orientation, deg:	(0,90), (18,72), (36,54)
Spacing, in.	10, 20, 40, 80

---

1 Zaker, T. A., "Blast Pressures from Sequential Explosions," Final Report J6166, IIT Research Institute, October 1969.

2. EXPERIMENTS

Pressure-time and impulse-time histories were recorded at 12 specific locations for each test so that peak pressures, peak impulse, time of arrival, and shock wave separation time and coalescence could be determined for the parameter variations.

2.1 Test Arrangement

A schematic diagram of the physical arrangement of the test setup is shown as Figure 1. The area consists of two 75-ft-long by 10-ft-wide concrete slabs located at right angles to one another. Pressure transducers were installed flush with the top surface of the concrete slabs in mechanically isolated steel plates. The steel plates cover a channel in which gage leads are laid. Further isolation of the gages occurs because the pressure transducers are installed in mylar mounting plugs. Pressure gages were located on both concrete slabs at the same relative distances with respect to the center.

The center area of the test setup, at the common ends of the concrete slabs, is sand. The explosive charges were placed in this area. Before each test this area was leveled even with the two concrete slabs. Zero distance was measured at the intersection of the centerlines of the two concrete slabs. The charges were equally spaced from this point.

Each charge was taped to a 6 by 6 by 0.5-in. steel plate. The charges were always separated by a 1-in.-thick steel dividing wall. The dividing wall was located at the center of the charge area and was oriented normal to a centerline through the charges. The dividing wall had four legs that were driven into the sand to minimize its movement. The dividing wall was used to minimize the possibility of sympathetic detonation of the second charge.

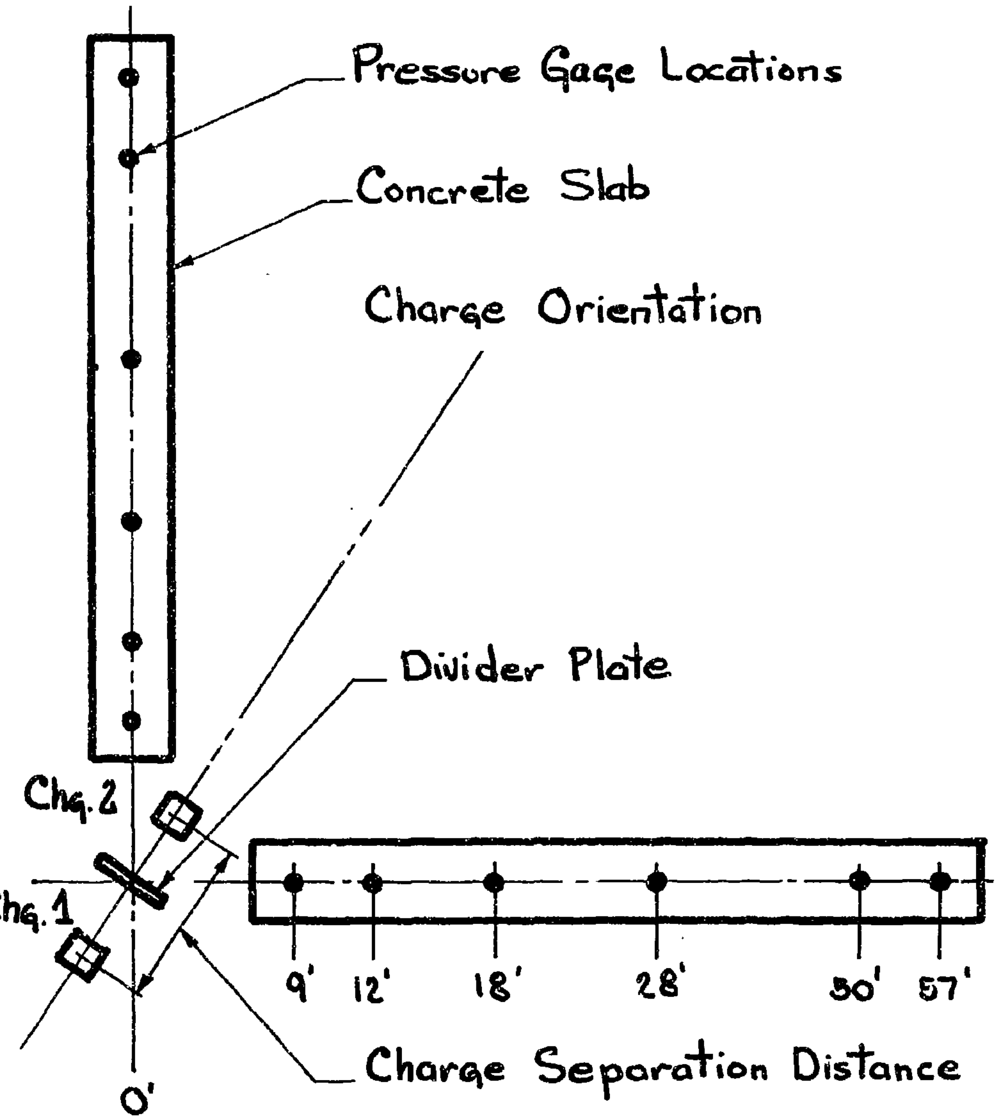


Figure 1

SEQUENTIAL EXPLOSION TEST SETUP

2.2 Explosive Charges

Two 1-lb hemispherical charges of C-4 plastic explosive (91 percent RDX and 9 percent plasticizer) were used for all tests. These charges were formed by pressing a pre-weighed quantity of explosive into a specially fabricated mold. The 1-lb charges are approximately 4-in. in diameter and are initiated with fast-functioning 106B National Northern Detonators using 0.25 by 0.25-in. cylindrical tetryl pellets as boosters.

The time delay between the first and second detonation was obtained by using electronic waveform and pulse generators (Tektronix Type 162 and 161 respectively), to trigger a thratron-controlled 4 mfd. 330 volt firing circuit to energize the second detonator at the preselected time delay.

2.3 Instrumentation

Pressure-time functions were monitored at locations as previously described. The pressure-time signals were integrated to produce impulse-time functions. Data signals were recorded on magnetic tape and reproduced on an oscillograph recorder.

A simplified block diagram of the record/reproduce instrumentation system is shown as Figure 2. A single data channel is shown here. In the test program, 12 identical channels were used. In addition to the equipment described below, the monitoring and signal control equipment is also shown. The data channels were monitored and an electrical calibration signal was recorded on each data track immediately preceding each test run. The electrical calibration signal is a voltage simulation of a predetermined impulse or pressure level. This signal is used in data reduction and to verify the integrity of the record/reproduce system.

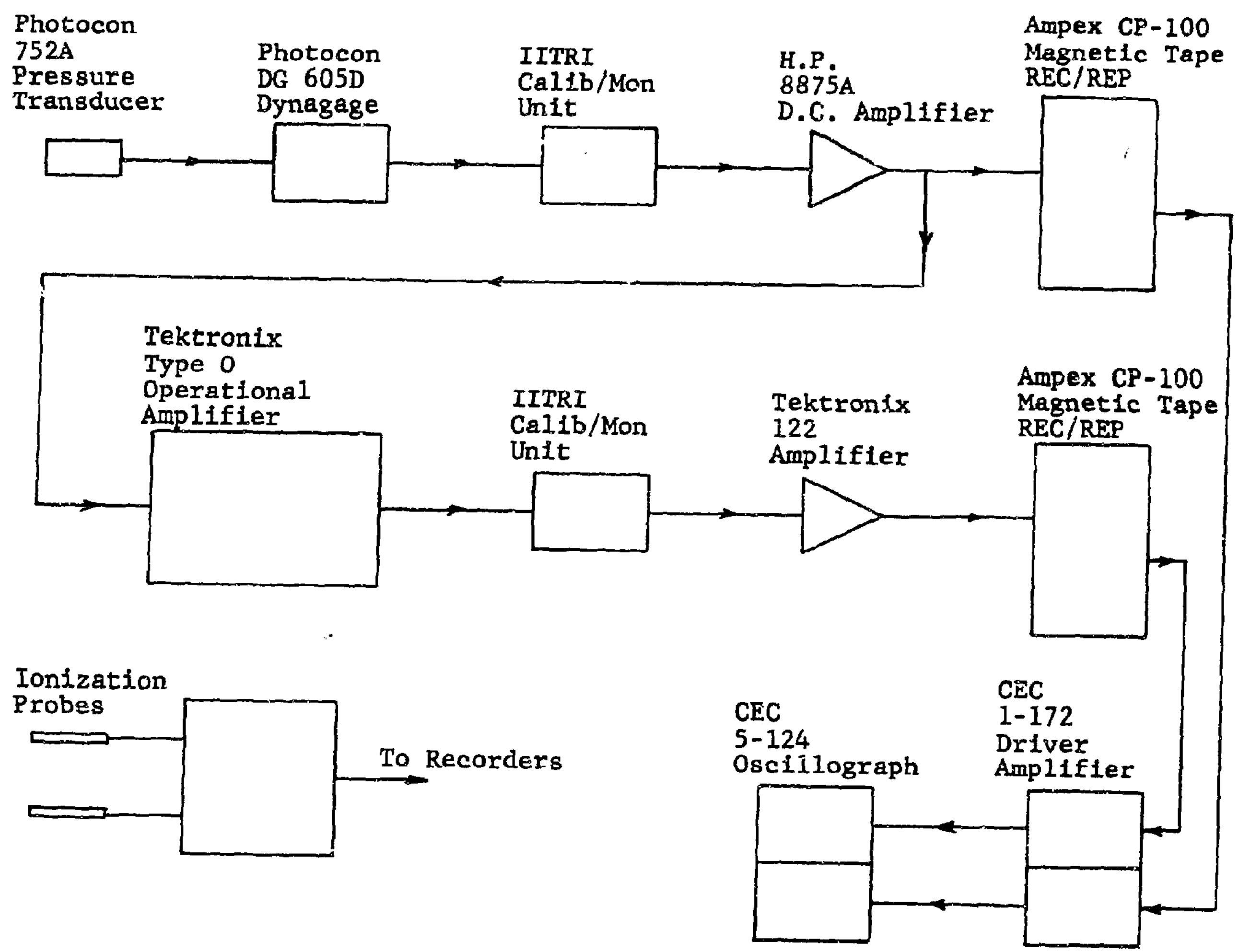


Figure 2 BLOCK DIAGRAM OF RECORD/REPRODUCE INSTRUMENTATION

The pressure measuring systems employed in the test program were manufactured by Photocon Research Products (PRP). These systems consist of three elements; the Dynagage (DG605D), a transmission line, and the pressure transducer (Type 752A).

Hewlett Packard (HP) Model 8875A differential amplifiers were used to condition the data signals for magnetic tape recording. These units were used to provide a voltage gain and impedance match between the pressure measuring system and magnetic tape recorder.

The data signals were recorded on an Ampex series CP-100 magnetic tape recorder. This unit is equipped with 13 FM recording tracks for data recording, and a single channel of direct recording for time base signals. The tape recorder conforms to specifications for the IRIG intermediate band.

The pressure impulse is defined as the area under the pressure-time history:

$$I(t) = \int_{t_o}^{t} P(t)\, dt$$

where P is the pressure and t is the time.

The signal voltage at the output of the Model 8875A amplifier is an electrical analog of the pressure-time history. This signal was used as input to a Tektronix Type O operational amplifier, where the electrical integration was performed. The integrated signal was amplified and in turn, recorded on a CP100 magnetic tape recorder.

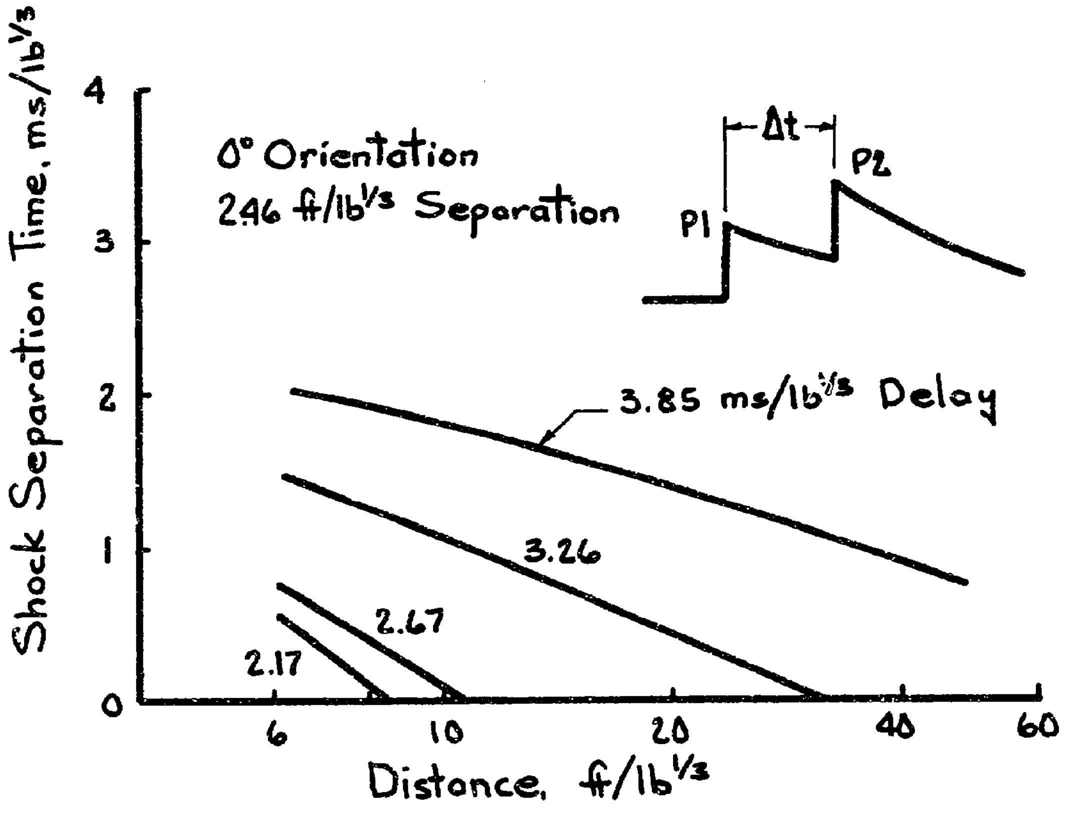
Oscillograph reproductions of the magnetic tape recordings were made by employing Consolidated Electrodynamics Corp. (CEC) Type 1-172 Driver Amplifiers to drive a CEC Type 5-124 Recording Oscillograph. The oscillograph was equipped with CEC Type 7-363 galvanometers.

The pressure data were recorded at a tape speed of 60 ips and reproduced at a tape speed of 1-7/8 ips, resulting in a frequency division of 32. The oscillograph paper speed was 32 ips. For these conditions, the oscillograph has a horizontal resolution of 976 μsec/in. and an effective frequency response from dc to 20 kHz, referred to real time.

3. EXPERIMENTAL RESULTS

Typical results are presented in the figures that follow. It is not the intent of this presentation to give all the experimental results obtained during the program. This paper briefly illustrates some of the parameter variations so as to give some insight to the problem. Interested personnel are advised to procure copies of a final report that will soon be published by IITRI for ASESB under the before mentioned contract. This final report will present complete details of the results.

Figure 3 illustrates shock separation time as a function of distance. Both the shock separation time and the distance from the charge at which coalescence occurs increases with increasing delay time. Zero shock separation time is coalescence. It should be noted that for long delay times the second shock will slow down with respect to the first shock because it is traveling in the negative velocity field of the first detonation.



0° Orientation
2.46 ft/lb$^{1/3}$ Separation
Δt
P1
P2
3.85 ms/lb$^{1/3}$ Delay
3.26
2.67
2.17
Shock Separation Time, ms/lb$^{1/3}$
0
1
2
3
4
6
10
20
40
60
Distance, ft/lb$^{1/3}$

Figure 3

Figure 4 illustrates typical shock coalescence contours for two specific charge separations. When the charges are close together coalescence occurs further away in the 0 degree orientation as compared to widely spaced charges. This of course is due to the fact that the second charge is physically further from the first shock. The physical separation of the charges has a less pronounced effect on shock coalescence in the 90 degree orientation. Figure 5 illustrates graphically the effect of charge separation on shock coalescence. Shown are curves of the delay time required to obtain shock coalescence at a specific radial distance from the charges (i.e., 20 $ft/lb^{1/3}$ radial distance). Note that there is a specific charge separation distance for which the minimum delay time is obtained. Namely, between a charge separation distance of 1.23 and 2.46 $ft/lb^{1/3}$ for angles less than approximately 70 degrees.

Figure 6 is an example of peak shock pressures as a function of delay time and distance. The first shock P1 obviously is constant with respect to delay time at a given distance. The peak pressure of the second shock does however vary with delay time at any given distance. Superimposed of this figure is a curve indicating the peak pressure at shock coalescence. Note that the maximum pressure does not occur when the two shocks coalesce at a particular distance. In this case the maximum pressure occurs when the shocks have coalesced before reaching the particular distance. There are parameter combinations wherein the reverse of this was also observed.

Figure 7 illustrates the necessity of this particular work. The solid line is the pressure-distance relationship of a single 2-lb charge. The two dashed lines are the pressure-distance curves for two 1-lb charges separated and detonated at the delay time indicated. Note that the peak

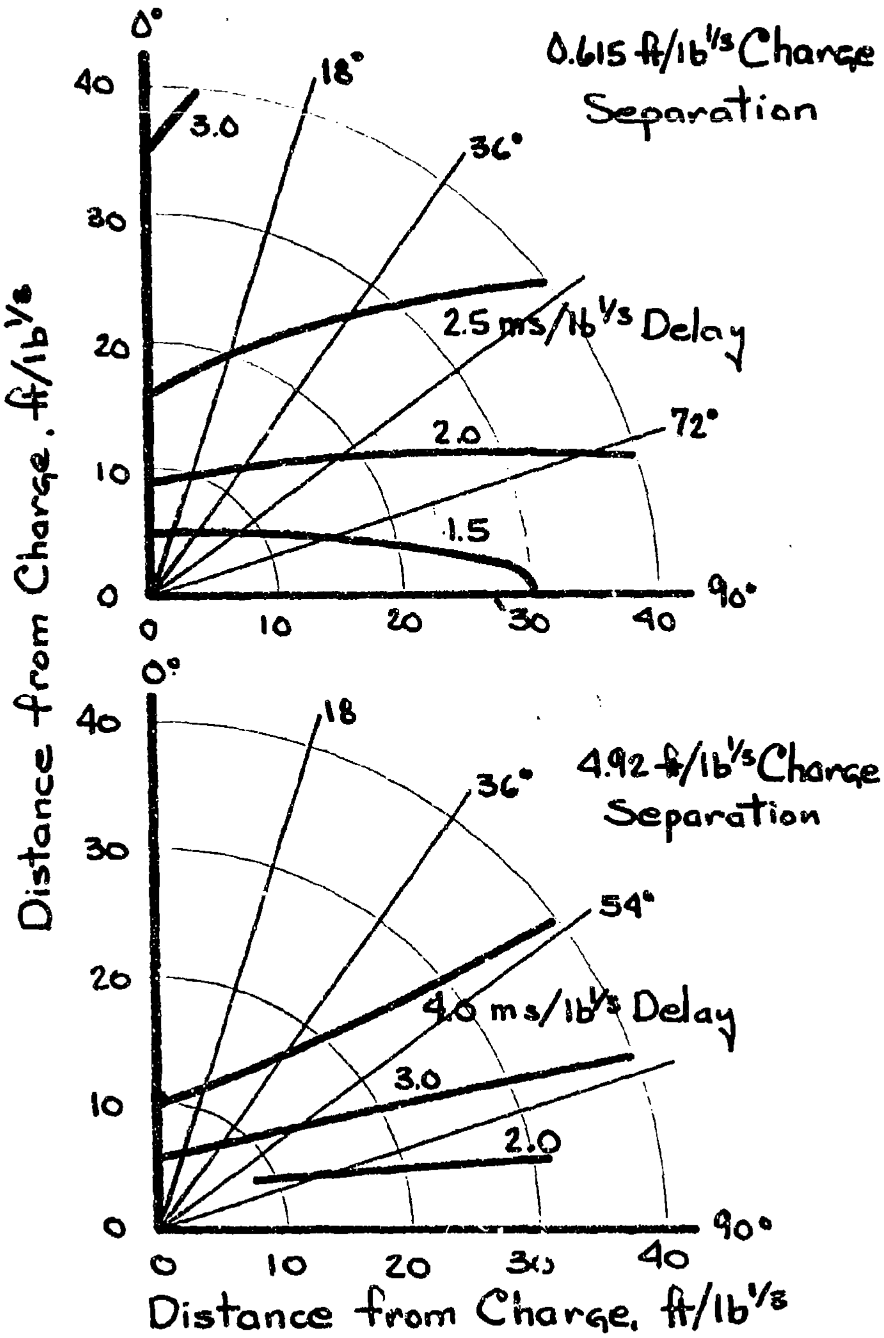


Figure 4

DELAY TIME FOR COALESCENCE

Coalescence @ 20 ft/lb$^{1/3}$ Radial Distance

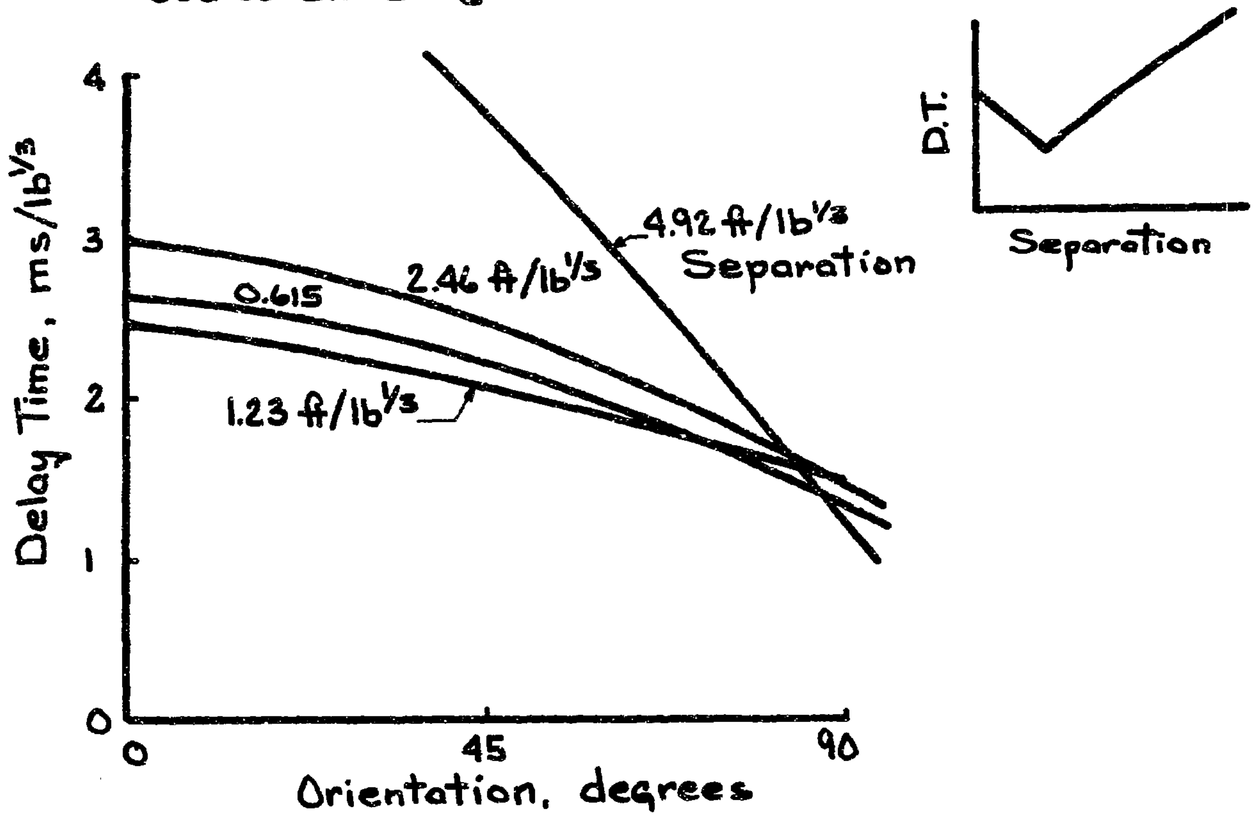
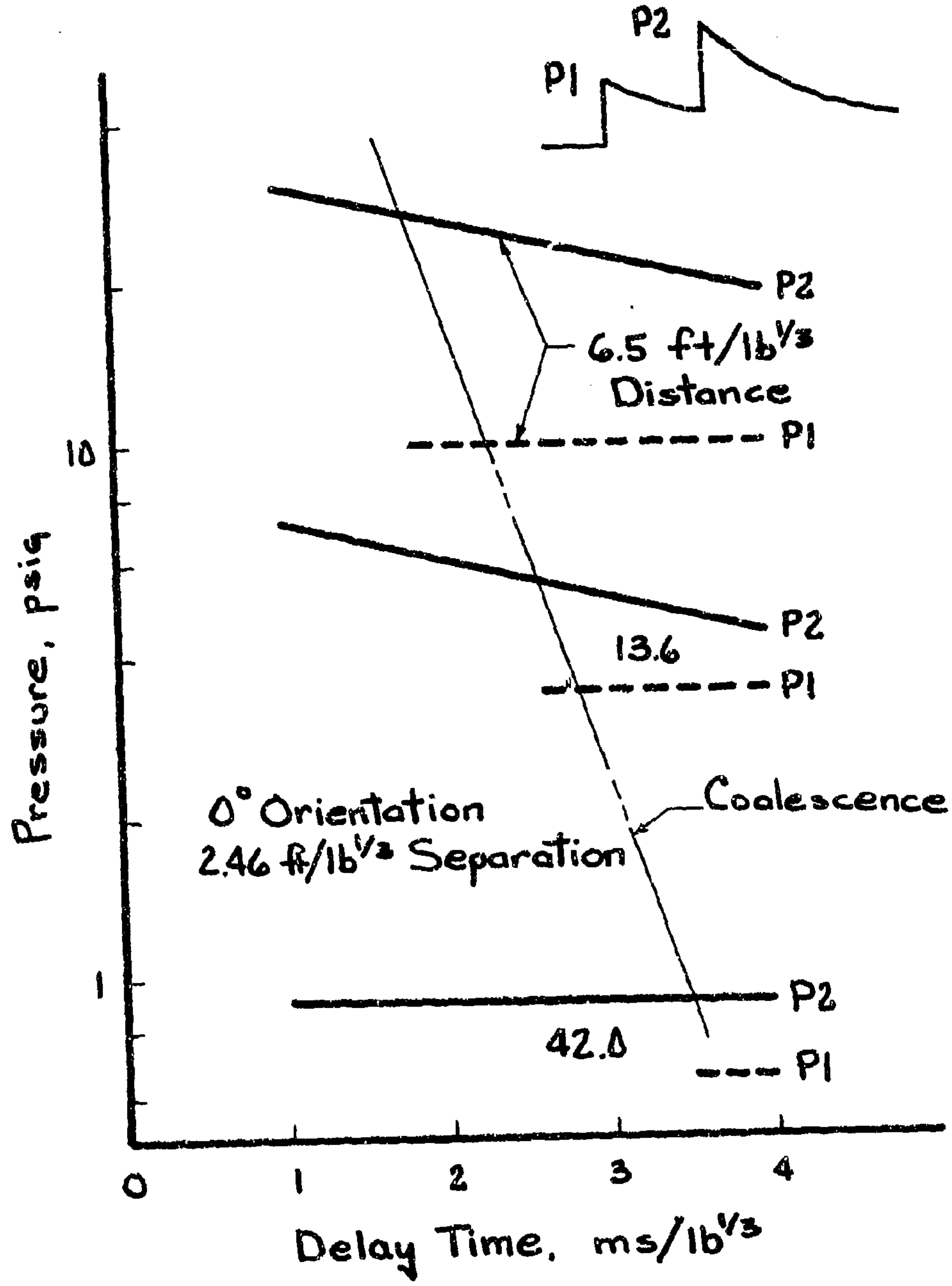


Figure 5



P2
P1
P2
6.5 ft/lb^1/3
Distance
10
P1
P2
13.6
P1
Pressure, psig
0° Orientation
2.46 ft/lb^1/3 Separation
Coalescence
1
P2
42.0
P1
0
1
2
3
4
Delay Time, ms/lb^1/3

Figure 6

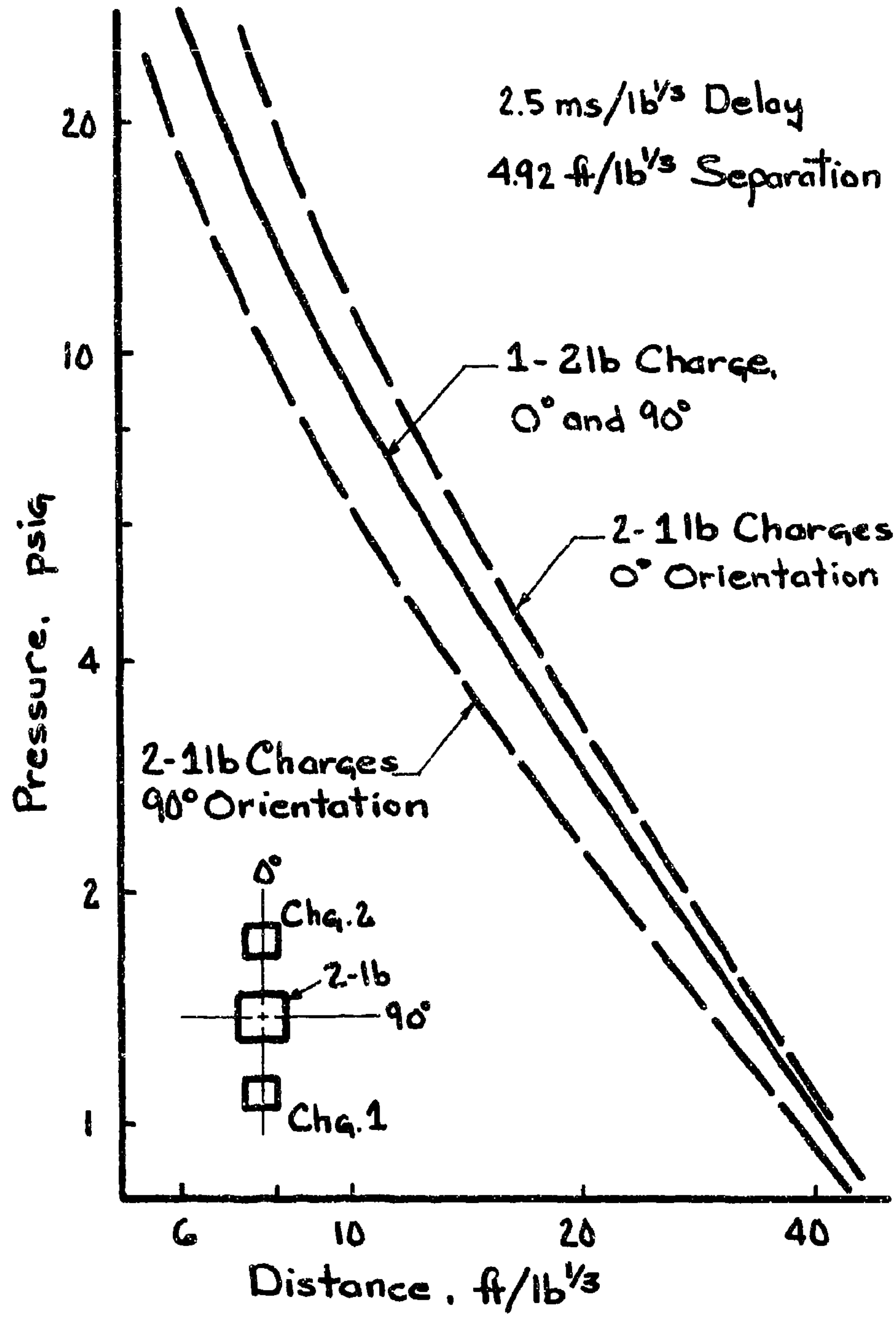

2.5 ms/lb^1/3 Delay
4.92 ft/lb^1/3 Separation
1- 2lb Charge, 0° and 90°
2- 1lb Charges 0° Orientation
2-1lb Charges 90° Orientation
0°
Chg. 2
2-lb
90°
Chg. 1
Pressure, psig
20
10
4
2
1
6
10
20
40
Distance, ft/lb^1/3

Figure 7

pressure measured in the 0 degree orientation is greater than that measured from a single 2-lb charge. Pressures measured in the 90 degree orientation are less for the two 1-lb charges than for the single 2-lb charge. This example illustrates that the degree of vulnerability in the 0 degree orientation is less if the total quantity of explosives are stored together. This however is not the case in the 90 degree orientation.

The example of Figure 7 also indicates that one cannot make quantity-distance storage estimates based on pressure-distance relationships assuming the total quantity of explosive is stored unseparated. Secondly it would be too conservative to assume the total quantity of explosives is stored at charge 2 location.

Figure 8 illustrates peak pressure-distance contours for a charge separation distance of 4.92 ft/lb$^{1/3}$ and a delay time of 2.5 ms/lb$^{1/3}$. One notes that lines of constant pressure are very circular with the exception of the 90 degree orientation. Superimposed on this figure are constant pressure lines (dashed) from a single two pound charge detonated at zero distance.

Peak Pressure Contour

4.92 ft/lb$^{1/3}$ Charge Separation

2.5 ms/lb$^{1/3}$ Delay Time

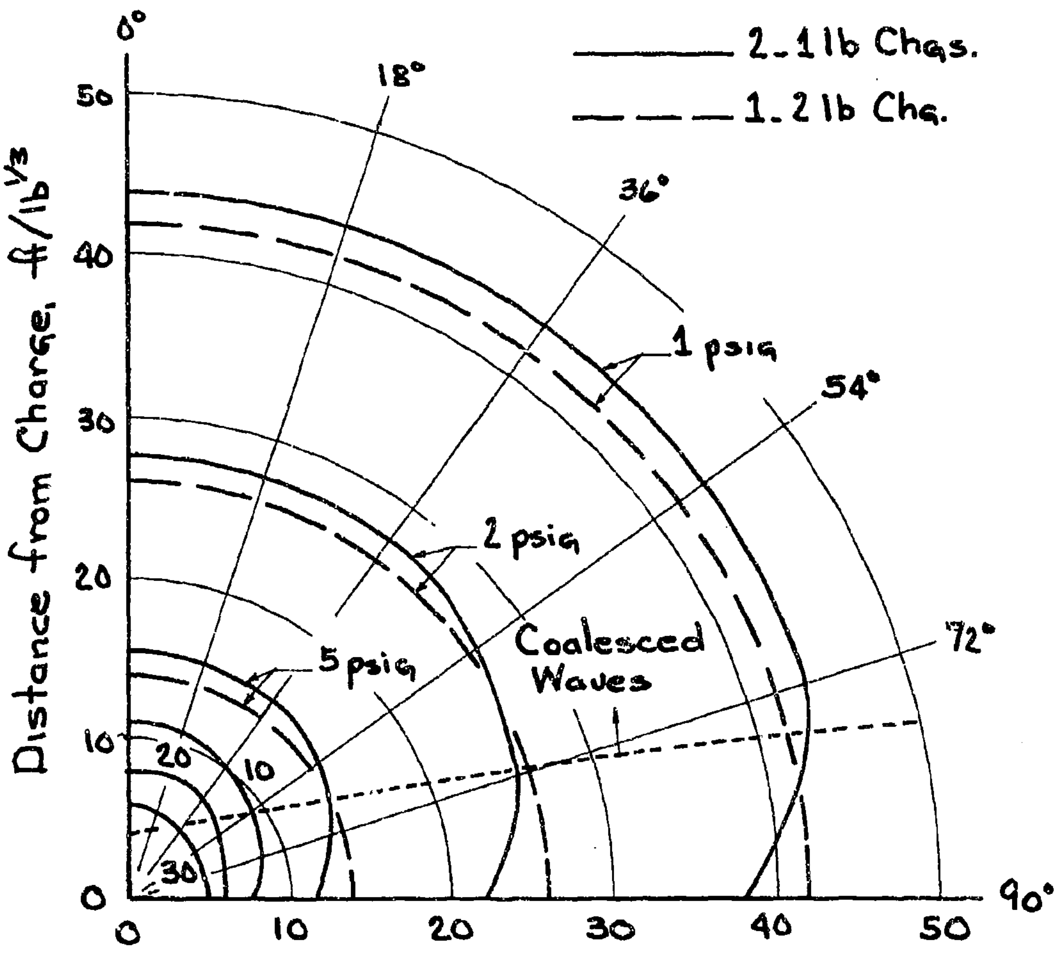


Figure 8

EXPLOSIVE YIELD CRITERIA STUDIES AT THE BALLISTIC RESEARCH LABORATORIES

George D. Teel

I have been asked to report on the studies recently completed and currently under way, at the Ballistic Research Laboratories, in support of, and funded by, the Armed Services Explosives Safety Board. It has long been an accepted fact that charge geometry and charge orientation affect the air blast field generated by the charge detonation, and that comparisons of air blast data, for the determination of explosive yield, should be made between information derived from similar charge geometries and orientations. The air blast fields and yield scaling laws have been well documented for hemispherical and spherical geometries and for the effects of charge orientation, specifically the height of burst.

In 1970 the BRL initiated a study to search for and collect the data available within the blast and shock community on the air blast effects of other geometrical shapes. Information on the air blast fields generated by the detonation of cylindrical and conical charges, placed on or very near the ground surface, was of prime interest since these geometries and orientations are typical of a large number of ordnance end items for which explosive equivalencies are desired. The study consisted of a search of available and existing literature and personal contact with agencies and organizations whose published literature indicated that unpublished information pertinent to the question might exist.

During the course of this phase of the study it became obvious that very little information was available on this particular problem. A rather large amount of experimental data was available from the Denver Research Institute on the detonation of cylindrical charges in free air and a limited amount of experimental work has been done by the Naval Ordnance Laboratory and the BRL with cylindrical charges resting on the

the ground surface with the charge axis vertical, or perpendicular to the surface. No information was located for charges detonated on and parallel to the ground surface, or with the charge axis at some oblique angle to the surface. Similarily, information on charges with a conical geometry was found to be lacking.

As a result of the first phase of the study, it was decided to initiate a series of small scale tests at the BRL. Initially the program will be limited to a study of the air blast effects around cylindrical charges. The charge weight will remain constant throughout the test series and the variable test parameters will be, length-to-diameter ratio of the charge, the charge orientation, and the point of initiation. Figure 1 shows the test set-up and the variables to be considered.

Eight pound cast pentolite charges with length-to-diameter ratios of 3, 6, and 12 will be utilized in all tests currently scheduled. Physically these charges will be; 3.8 inches in diameter by 11.5 inches long for the $L/D = 3$, 3.1 inches by 18.3 inches for $L/D = 6$, and 2.4 inches by 29.1 inches for $L/D = 12$. Because of the difficulty in casting and handling long, slender charges, the longer charges will be cast in segments and joined with explosive cement for testing. All charges will have single point, end initiation. The variables in the tests will be the length-to-diameter ratio, L/D, the angle of the charge axis with the horizontal, α, and the angle between the horizontal projection of the charge axis and the instrumentation line, ϕ. As noted, the charges will be placed with the center of gravity above the working point.

Of the total program of 50 tests, 30 are currently outlined as shown in Figure 2. The program is divided into three major phases with the charges oriented in a vertical position for the

first phase, horizontal in the second phase, and with the charge axis at 45° to the horizontal in the final portion. The three phases represent launch orientations in phases one and three and the assembly, transportation, and storage modes in phase two.

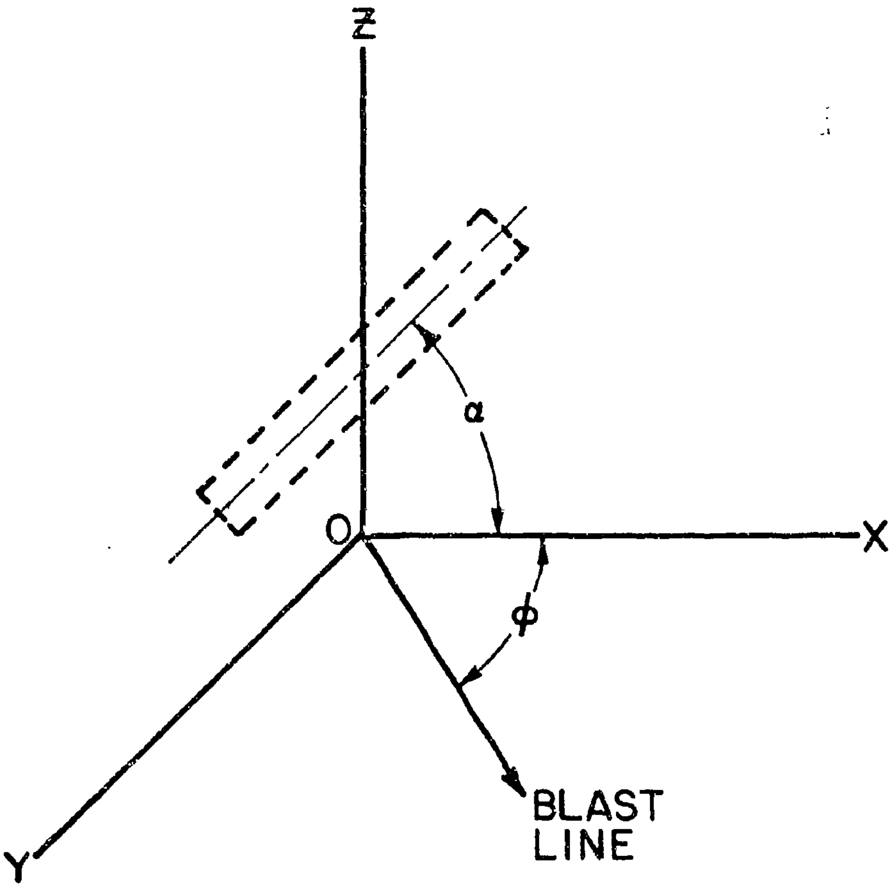
The tests outlined for phase one are primarily designed to provide data for correlation with the previous work at the NOL and BRL. Throughout the program, the test outline will be constantly reviewed and will be modified at the discretion of the ASESB and BRL. If at any point in a particular phase of the program a maximization of effects is reached, that particular phase will be concluded and the remaining tests rescheduled to provide a maximum information yield from the program.

Ten to twelve channels of pressure-time data will be recorded on each test and the charges will be rotated in phases two and three to acquire data at various angles with respect to the charge axis. Piezo-electric pressure transducers (250 KHz natural frequency) will be recorded on magnetic tape. The tape recorder is equipped with medium band, 80 KHz, FM electronics.

During the course of the past work done at the BRL, the curve shown in Figure 3 was developed. This curve, based on an idealized recording system, indicates that an 80 KHz bandwidth system would yield data, for a 1 pound charge from 1 to 100 psi peak overpressure, with a maximum loss of peak overpressure due to frequency response of approximately 5%. Since this curve scales as the cube root of the charge weight, $W^{1/3}$, we can then consider our recording system as having a bandwidth of 160 KHz, for the eight pound charges to be used, and therefore expect that the error in peak pressure, due to system response, measured in this program will be less than 3%.

It is not expected that this limited program will provide

the answers to all of the questions outstanding on the problem of the air blast fields around charges of various geometrical shapes and solve all of the problems in the determination of the explosive equivalencies of ordnance items. It should however provide a significant amount of information not currently available on the air blast effects of cylindrical charges. It is anticipated that a great many questions will remain unanswered at the conclusion of this particular test series, but the information gained should provide excellent direction for future investigations.



α = ANGLE BETWEEN CHARGE AXIS & GROUND SURFACE

ϕ = ANGLE BETWEEN HORIZONTAL PROJECTION OF CHARGE AXIS & INSTRUMENTATION LINE

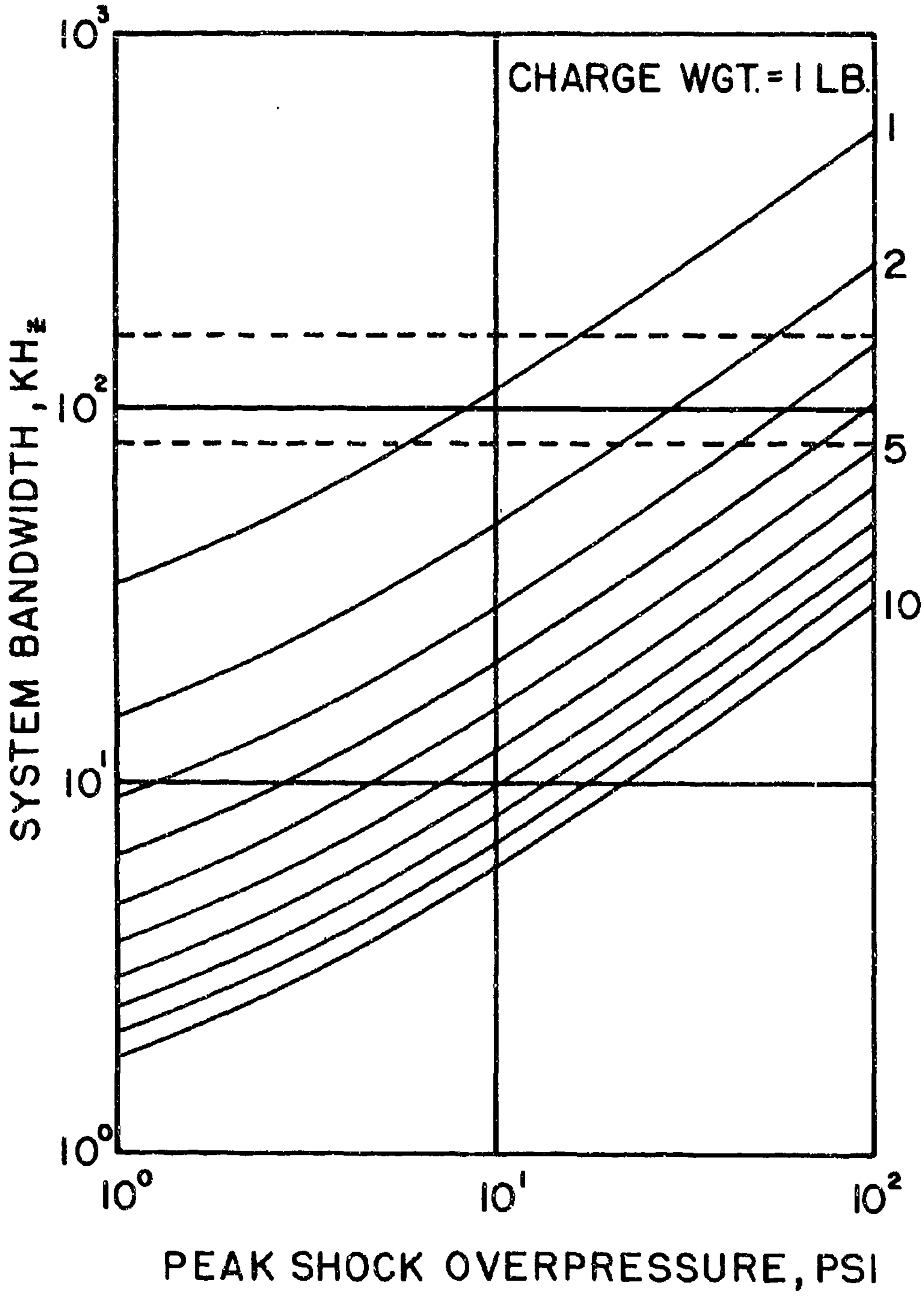
NOTE: ALL CHARGES POSITIONED WITH CG OVER ORIGIN OF COORDINATE SYSTEM

PROGRAM OUTLINE

PHASE	α	INITIATION POINT	L/D	ϕ	# TESTS
1	90°	TOP	3	0°	3
	"	"	6	"	"
	"	BOTTOM	"	"	"
	"	"	3	"	"
	"	"	12	"	"*
2	0°	180°	12	0°	2
	"	"	"	45°	"
	"	"	"	90°	"
	"	"	"	135°	"
	"	"	"	180°	"
	"	"	6	0°	"
	"	"	"	45°	"
	"	"	"	90°	"
	"	"	"	135°	"
	"	"	"	180°	"
	"	"	3	0°	"
	"	"	"	45°	"
	"	"	"	90°	"
	"	"	"	135°	"
	"	"	"	180°	"
3**	45°	180°			

* TENTATIVE

** THESE TESTS WILL BE SCHEDULED AT A LATER TIME AND WILL BE BASED ON THE RESULTS OF GROUPS 1 AND 2.



CHARGE WGT. = 1 LB.
SYSTEM BANDWIDTH, KHz
% OF PRESSURE LOST
1
2
5
10
10^0
10^1
10^2
10^3
PEAK SHOCK OVERPRESSURE, PSI

TRAJECTORY CALCULATIONS

IN FRAGMENT HAZARD ANALYSIS

T. A. Zaker
Chief Explosives Scientist
Armed Services Explosives Safety Board
August 1971
Revised September 1971

Estimates of the effectiveness of fragmenting weapons against military targets are generally based on the assumption that the fragments travel in straight lines, retarded by aerodynamic drag force alone. In calculations of fragment hazards from accidental explosions to exposed persons in the far field, however, the effect of gravity on the fragment trajectories cannot be neglected. Accurate determination of the trajectories is essential to attaining sufficient consistency in computations of fragment number density at distances from the explosion. Owing to the volume of trajectory information which must be processed in fragment field calculations, it is desirable to attain this accuracy with economy of computing effort as well.

In this paper, difference equations for efficient numerical determination of ballistic trajectories are formulated from a local perturbation solution of the equations of motion. The local solution is obtained by regarding gravity as a perturbing effect on the straight trajectory which results when aerodynamic drag alone is considered. Comparisons of terminal ballistic parameters computed using this numerical method are made with the results of limiting cases solvable analytically, and with results computed using a standard numerical scheme. The new method is shown to be particularly useful for estimating fragment effects in the near field,

where the fragment density depends sensitively on the initial trajectory parameters of fragments launched at small elevation angles.

PERTURBATION TECHNIQUE

The equations of motion of a fragment moving under the influence of aerodynamic drag and gravity forces, in stationary local coordinates $\bar{x}$, $\bar{y}$ tangent and normal to the trajectory (Figure 1), are

$$\ddot{\bar{x}} + \beta v \dot{\bar{x}} + g \sin\alpha = 0 \tag{1}$$

$$\ddot{\bar{y}} + \beta v \dot{\bar{y}} + g \cos\alpha = 0 \tag{2}$$

where dots denote differentiation with respect to time t. In these equations, g is the acceleration of gravity, v is the speed in the path, and α is the angle between the $\bar{x}$ - axis and the horizontal. Instantaneously we have $\dot{\bar{x}} = v$ and $\dot{\bar{y}} = 0$.

The aerodynamic coefficient β is given by

$$\beta = C_d \, w \, A/2W \tag{3}$$

where C_d is the drag coefficient, w is the specific weight of air, A is the cross-sectional area of the fragment normal to the flight direction, and W is the fragment weight. The fragment area and weight are related empirically [1*] through a ballistic density k as follows:

$$W = kA^{3/2} \tag{4}$$

In terms of k, the aerodynamic coefficient becomes

$$\beta = C_d w/2(k^2 W)^{1/3} \tag{5}$$

An approximate local solution to the equations of motion is obtained by separating the displacement into two parts, one a basic solution satisfying the local initial conditions and the equations of motion with

*Superscript numerals designate appended references.

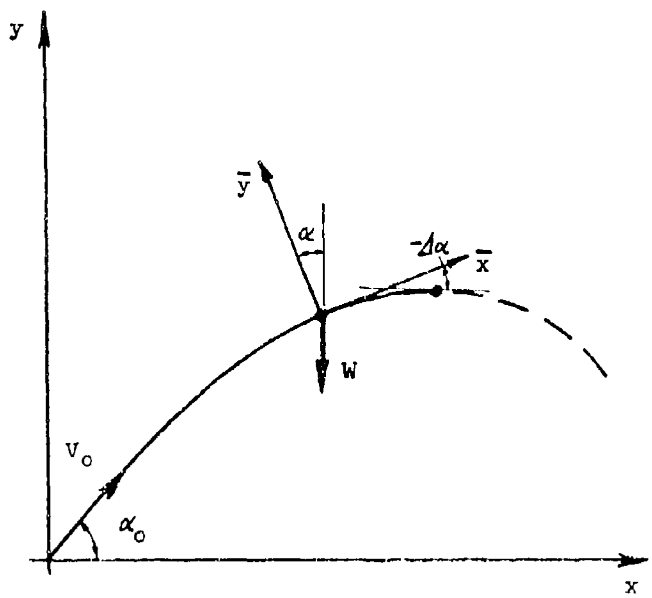


Figure 1 Coordinate Systems and Trajectory Geometry

gravity absent, and the other a pair of perturbations satisfying the linearized residual equations. The results, applicable for small departures of the trajectory from the local initial tangent, are equivalent to difference equations appropriate to an arbitrary time step in a numerical integration of the complete trajectory.

Gravity Free Solution

The displacement $\bar{x}$ is assumed to be of the form

$$\bar{x} = \bar{x}_o + \bar{x}_p \tag{6}$$

where the basic solution $\bar{x}_o$ satisfies the equation

$$\ddot{\bar{x}}_o + \beta \dot{\bar{x}}_o^2 = 0 \tag{7}$$

and the initial condition $\dot{\bar{x}}_o = v$, while the perturbation $\bar{x}_p$ satisfies the associated residual of Equation (1).

The drag coefficient C_d in general depends on the Mach number, and the atmospheric weight density w is a function of altitude. If both of these factors are assumed to be constant during the time interval of interest, however, the aerodynamic coefficient β is a constant and Equation (7) is easily integrated. The results are

$$\bar{x}_o = [\log(1+u)]/\beta \tag{8}$$

$$\dot{\bar{x}}_o = v_o/(1+u) \tag{9}$$

where

$$u = \beta v_o t \tag{10}$$

In these expressions, t is measured from the time at which the fragment is at the local coordinate origin in Figure 1, and v_o is the value of v at that time.

Perturbed Solution

Substituting Equations (6) and (7) into the equations of motion, expanding v in binomial series, and neglecting terms of second order and higher in $\dot{\bar{x}}_p$ and $\dot{\bar{y}}$, we reach the following results:

$$\ddot{\bar{x}}_p + 2\beta\dot{\bar{x}}_o\dot{\bar{x}}_p + g\sin\alpha = 0 \tag{11}$$

$$\ddot{\bar{y}} + \beta\dot{\bar{x}}_o\dot{\bar{y}} + g\cos\alpha = 0 \tag{12}$$

These equations are linear in the displacement perturbations $\bar{x}_p$ and $\bar{y}$, and can be integrated analytically by standard methods. The displacement and velocity perturbations are

$$\bar{x}_p = -(g/2)t^2\sin\alpha(1+u/3)/(1+u) \tag{13}$$

$$\bar{y} = -(g/2)t^2\cos\alpha\left[u(1+u/2)-\log(1+u)\right]/u^2 \tag{14}$$

$$\dot{\bar{x}}_p = -gt\sin\alpha\left[1+u(1+u/3)\right]/(1+u)^2 \tag{15}$$

$$\dot{\bar{y}} = -gt\cos\alpha(1+u/2)/(1+u) \tag{16}$$

where u is defined as before by Equation (10).

The leading factors on the right in the foregoing equations express the position and velocity changes due to gravity in the elementary case of a drag-free trajectory. The multipliers containing u all approach unity as u vanishes, and can be viewed as corrections on the effect of gravity due to drag.

Numerical Method

The drag coefficient and atmospheric density are assumed to be constant during each time step at their values at the beginning of the step. The method is self-starting in that the position and velocity changes are computed from initial values at the current step only.

Difference Equations. Initial values $v = V_o$ and $\alpha = \alpha_o$ are assumed to be given at the fixed coordinate origin in Figure 1. Equations (8), (9), and (13) through (16) give directly the displacement and velocity components after a typical time step t in the local coordinates. With respect to the fixed coordinates, the displacements during the time step are obtained from the relations

$$\Delta x = \bar{x} \cos\alpha - \bar{y} \sin\alpha \tag{17}$$

$$\Delta y = \bar{x} \sin\alpha + \bar{y} \cos\alpha \tag{18}$$

while the rotation of the trajectory tangent is given by

$$\Delta\alpha = \tan^{-1}(\dot{\bar{y}}/\dot{\bar{x}}) \tag{19}$$

Though derived by treating gravity as a perturbing effect on a straight, drag-influenced trajectory, this formulation is exact in the drag-free limit. If $\beta = 0$, however, $\bar{x}_o$ must be computed as its limit $v_o t$ rather than from Equation (8). Moreover, to avoid a loss of precision in calculating $\bar{y}$ from Equation (14) for small values of u, the multiplier containing u must be replaced by a truncated series expansion. For example, using equipment and procedures which retain 11 decimal digits, at $u = 10^{-4}$ the two-term expansion $(1 - u/3)$ gives the same precision (7 digits) as does evaluating the expression as it stands.

Accuracy. The terms of lowest order in $\dot{\bar{x}}_p$ and $\dot{\bar{y}}$ that are neglected in the linearization leading to Equations (11) and (12) are

$$\beta(\dot{\bar{x}}_p^2 + \dot{\bar{y}}^2/2) \text{ and } \beta\dot{\bar{x}}_p \dot{\bar{y}},$$

respectively. To estimate the corresponding truncation error of the numerical method, define the parameter $G = g/\beta v_o^2$. Then, relative to mutually

cancelling terms of order unity (from the basic solution) and of order G (from the perturbations), the results fail to satisfy the full equations of motion by the nondimensional residuals

$$e_x = G^2u^2(3-\cos 2\alpha)/4 \qquad (20)$$

$$e_y = G^2u^2 \sin 2\alpha/2 \qquad (21)$$

to lowest order in u. The truncation error is therefore of the order of the square of the time step t.

To keep the residuals at each step small compared with terms of order G, we must have $Gu^2 \ll 1$, and therefore

$$t \ll (\beta g)^{-1/2} \qquad (22)$$

This requirement is independent of the velocity, and suggests that a uniform time step is suitable for numerically integrating the complete trajectory, at least if G is small. Furthermore, when G becomes large, the difference equations approach the correct limits for a drag-free trajectory exactly, as has already been noted.

COMPARISONS AND APPLICATIONS

Performance Comparisons

Accuracy and other aspects of the performance of the numerical scheme were tested against limiting cases for which exact solutions are available, and against results obtained by a standard numerical method.

Vertical Trajectory. With a constant aerodynamic coefficient β, an exact solution exists for the case of fragments projected vertically upward. This furnishes a useful test of numerical results for the same case. Define the following dimensionless quantities:

$$Y = \beta y \qquad (23)$$

$$T = t(\beta g)^{1/2} \qquad (24)$$

$$V = V_o(\beta/g)^{1/2} \qquad (25)$$

where $y = 0$ and $v = V_o$ at $t = 0$.

On the upward-going branch of the trajectory, $T \leq \tan^{-1}V$, and the position and velocity are given by

$$Y = \log\left[(1 + V^2)^{1/2} \cos(\tan^{-1}V - T)\right] \qquad (26)$$

$$dY/dT = \tan(\tan^{-1}V - T) \qquad (27)$$

On the downward-going branch, $T \geq \tan^{-1}V$, and the results are

$$Y = -\log\left[(1 + V^2)^{1/2} \cosh(T - \tan^{-1}V)\right] \qquad (28)$$

$$dY/dT = -\tanh(T - \tan^{-1}V) \qquad (29)$$

All properties of the trajectory, including maximum height, time of flight, and impact speed when $y = 0$ are readily obtained from these formulas.

Numerical Comparisons. Trajectory calculations were made using both the numerical method based on the local perturbation solution and a standard fourth-order Runge-Kutta scheme. For purposes of comparison with analytic results where available, the aerodynamic coefficient was assumed constant throughout the trajectory. Incorporating a velocity-dependent drag coefficient in either method is equally straightforward, although in principle the Runge-Kutta method would represent this variation more accurately.

Both methods are self-starting, and both methods yield exact results in the drag-free limit independent of the choice of time step. In addition,

with a constant aerodynamic coefficient β the numerical perturbation method gives an exact result if gravity is absent.

Trajectory computations were performed covering initial velocities up to 10,000 ft/sec, launch angles from 10 to 90 degrees, and weight from 0.1 to 1 lb. A ballistic density of 660 grains/in^3 was used, and a drag coefficient equal to 1.28 was assumed. In the Runge-Kutta procedure, a variable time step, chosen in such a way that the fractional velocity change is approximately constant on any one trajectory, gives best results; with a constant time step the method fails at high (10,000 ft/sec) initial velocities. In the numerical perturbation scheme, a constant time step gives best results, although a variable time step yields adequate performance.

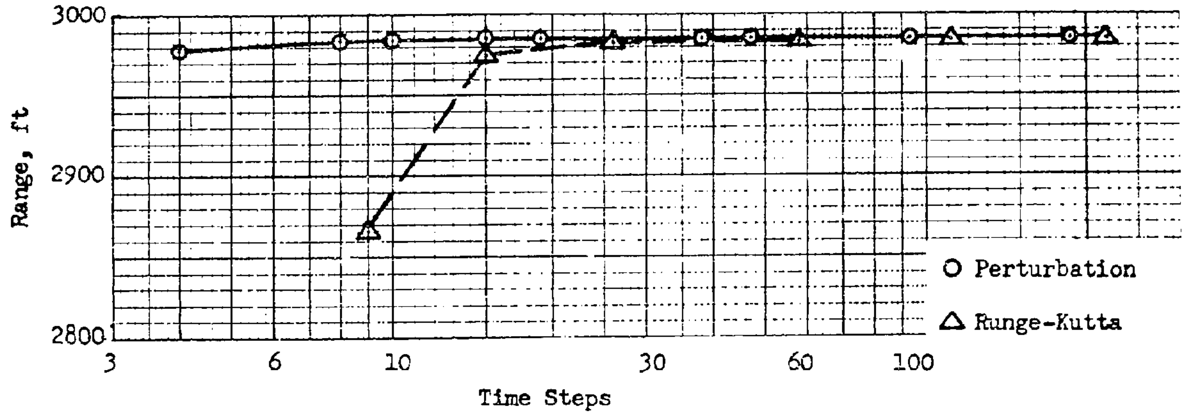
In general, it was observed that

- The two numerical methods give equally high precision for all trajectories when a large number of time steps (greater than 100) is used.

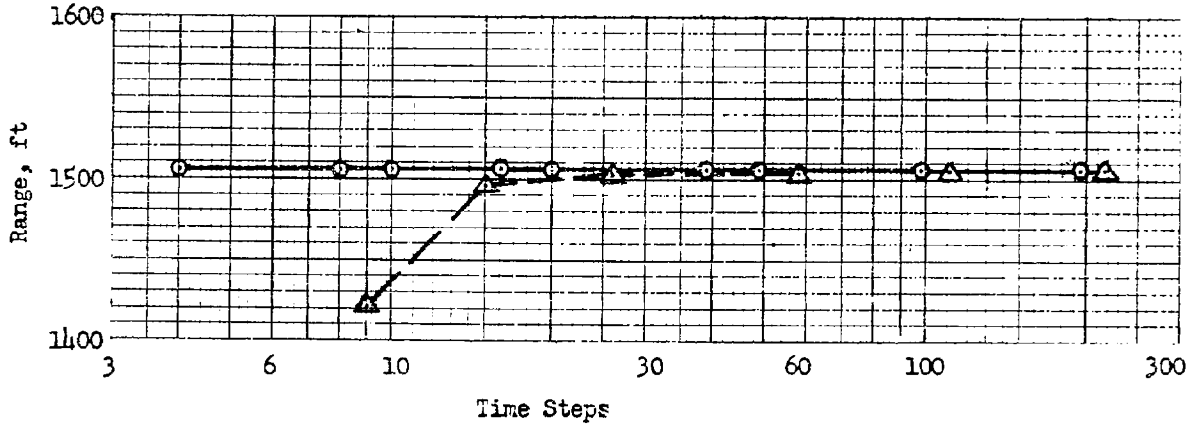
- As the number of time steps is decreased to a small value (less than 10), precision of the Runge-Kutta results declines significantly, while the numerical perturbation method continues to give acceptable results with only minor degradation of accuracy.

- The superior precision obtained using the numerical perturbation scheme is particularly evident at high initial velocities and low launch angles (less than 30 degrees).

A graphical comparison of fragment ranges computed by both numerical methods at various levels of trajectory resolution is shown in Figure 2 for relatively low-angle, high-velocity fragments. Results obtained



Fragment Weight 7000 grains



Fragment Weight 700 grains

Figure 2 Fragment Range for 10,000 fps Initial Velocity, 10 deg Launch Angle

using the numerical perturbation scheme at the coarsest resolution shown in Figure 2 correspond to a time step equal to half the time constant on the right in the inequality (22). The performance of the method can be expected to improve further as the launch angle and, accordingly, the departure of the complete trajectory from its initial tangent decrease to still lower values.

Fragment Hazard Analysis

For fragments launched at angles of at least 10 degrees, the velocity at impact is virtually independent of the initial velocity, and does not exceed $(g/\beta)^{1/2}$, the terminal velocity in free fall. In Figure 3 are shown comparisons of two terminal velocity-weight relations with injury criteria based on fragment energy. The intersections of the terminal velocity curves with the injury thresholds give lower bounds on the weight of falling fragments which can cause injury. For an injury criterion based on an impact energy of 58 ft-lb, it is evident that only those fragments of weight greater than about 2000 grains exceed the injury threshold. This lower bound on fragment weight is rather sensitive to the choice of energy level corresponding to the threshold of injury; for an injury criterion used in previous ASESB-supported work[2] based on an impact energy of 11 ft-lb, it is about 600 grains.

It has been observed by Banfield[3] that the effectiveness of attack by "upper-register" fragments (those launched at angles greater than that corresponding to maximum range) is much less than that of lower-register fragments. This is evidently because only the heaviest such fragments, which are few in number from a single round, have sufficient terminal energy in free fall to meet prescribed injury criteria. These arguments suggest that

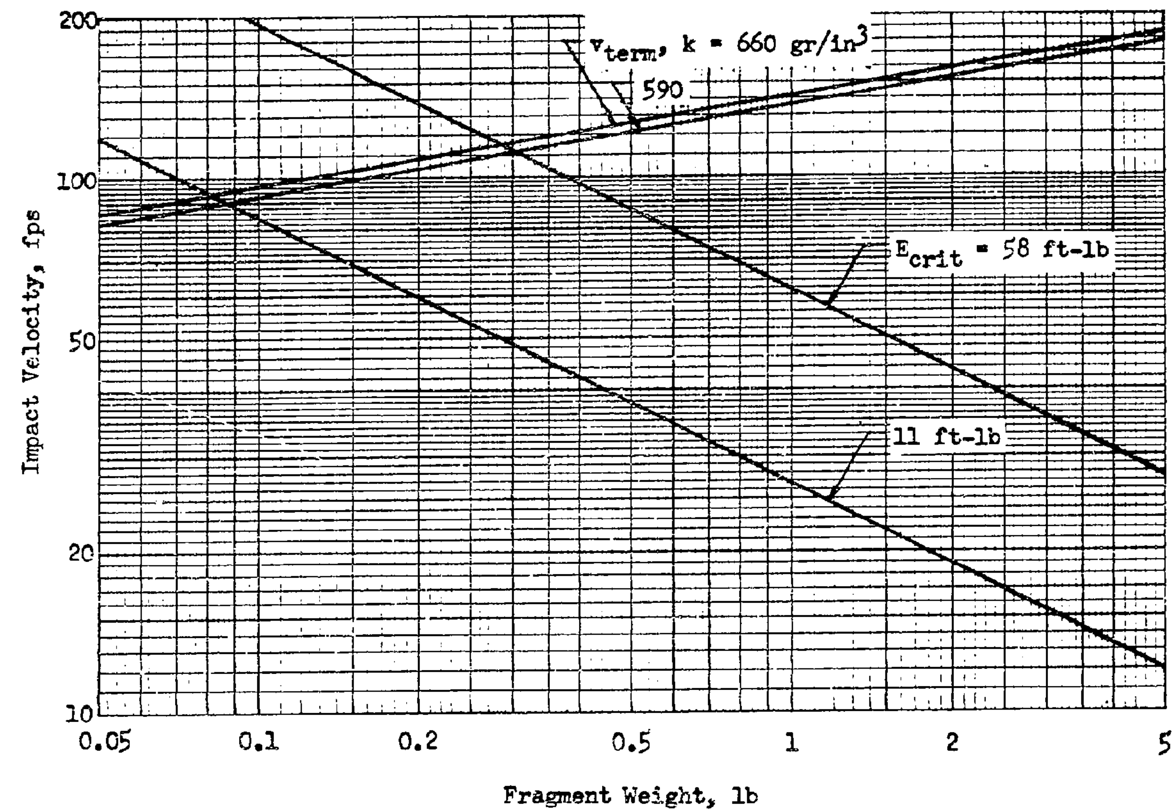


Figure 3 Injury Criteria and Terminal Velocities

- The upper end of the spectrum of fragment weight emitted by a weapon must be resolved accurately in order to account for the hazard of upper-register fragments from stacks of ammunition.

- Careful consideration should be given to the choice of fragment injury criterion in the context of its intended application to hazard analysis.

- Lower-register fragments may be decisive in determining the hazard of fragment injury to persons from stacks of ammunition. If this is in fact the case, accurate determination of lower-register trajectories and exposed target areas is essential.

Fragment number density at the ground surface is a sensitive function of the launch angle of lower-register fragments. To illustrate, consider a two-dimensional (cylindrical) fragment source of radius R_o as shown schematically in Figure 4. The number density n of lower-register fragments at the ground surface is given in terms of the density n_o at the source by

$$n = n_o R_o / (dR/d\alpha_o) \tag{30}$$

where R is the terminal point of the trajectory.

For low-angle trajectories, the analytic perturbation equations with $\alpha = \alpha_o$ furnish an approximate solution for the complete trajectory in one time step t, the total time of flight. An obvious criterion of applicability of the one-step solution is that the time of flight satisfy the inequality (22). At impact, the expressions for the position coordinates x and y are of the form

$$x = R(\alpha, t) \tag{31}$$

$$y = H(\alpha, t) = 0 \tag{32}$$

By differentiation, we obtain

$$dR/d\alpha = \partial R/\partial\alpha - (\partial R/\partial t)(\partial H/\partial\alpha)/(\partial H/\partial t) \tag{33}$$

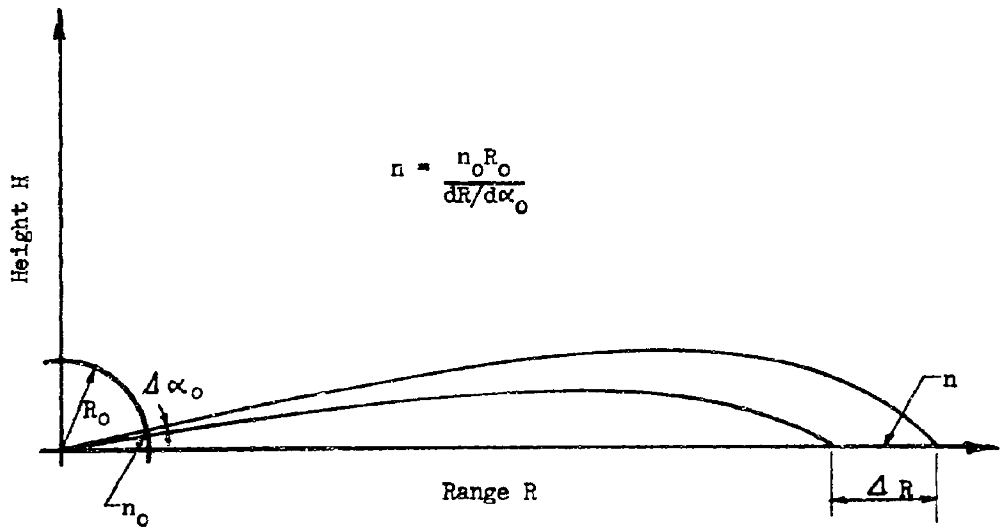


Figure 4 Fragment Density Mapping at Ground Plane

This equation can be evaluated directly once the time of flight is obtained by solving Equation (32). This furnishes a procedure for calculation of fragment number density that does not entail numerical differentiation of tabular results.

CONCLUSIONS

- The numerical scheme for integrating trajectory equations, developed in the present paper from a gravity-perturbed local analytic solution, furnishes precision superior to that of standard methods with economy of computing effort, particularly for fragments launched at low angles.

- Upper-register fragments, falling at impact, must be of the order of 0.1 lb or more in weight to exceed typical injury criteria.

- Good definition of the upper end of the fragment weight spectrum of weapons is essential to estimating the far-field hazard due to upper-register fragments from stacks of ammunition.

- The gravity-perturbed trajectory formulas provide a convenient approximate solution to the complete trajectories of lower-register fragments; this simplifies the calculation of fragment number density where it is sensitive to launch angle, and where target profile effects may be important.

REFERENCES

1. D. J. Dunn and W. R. Porter, "Air Drag Measurements of Fragments," BRL MR 915 (August 1955)

2. T. A. Zaker et al., "Fragmentation Hazard Study, Phases I and II: Single-Munition Fragment Hazards," Contract No. DAHC04-69-C-0056, IIT Research Institute (April 1970)

3. J. N. Banfield, "The Effect of the Neglect of Gravity on Computations of the Antipersonnel Lethality of HE Fragmenting Weapons," RARDE Memorandum 22/70 (September 1970) (C)

SLURRY EXPLOSIVES: Their Safety, Manufacture, Cost, and Versatility

IRECO Chemicals
Suite 726
Kennecott Building
Salt Lake City, Utah 84111

by M. Taylor Abegg, Vice President-R & D
& Gary M. Thornley, Director of Operations-Specialty Products

Slurry explosives (commercially termed "Slurries" and called GSX by the military) differ from conventional military explosives in that they are not specific chemical compounds, but are usually composed of mixtures of non-explosive, non-propellant materials described generally as oxidizers, fuels, thickeners, stabilizers, and a fluid phase (usually water), all in varying amounts.

The safety characteristics of slurries are related to physical as well as detonation properties, to the non-hazardous ingredients (usually none rated more hazardous than "oxidizer"), and the fluid phase which contributes plasticity and lessens the sensitivity to mechanical and high temperature initiation sources.

The versatility of slurries is demonstrated by the possible selection of various ingredient combinations to provide a wide range of physical and detonation properties. Detonation velocities range from 2300 to 6500 m/sec, heats of explosion from 700 to 2000 Kcal/Kgm, detonation pressures from 25 to 280 kilobars, and a wide range of sensitivities are available.

Mobile pump truck systems manufacture and deliver slurries at remote sites, as well as at plant type facilities. This has made possible the manufacture of slurries and the loading of ordnance in the area of use as well as at arsenals, thus decreasing mobilization and demobilization time and costs. Loading techniques have also been developed which leave no ullage in the slurry-filled container.

The low cost of slurries depends on the major ingredients, usually ammonium nitrate and aluminum powder, and the comparatively low labor factor made possible by the relatively simple slurry manufacturing process.

The many favorable attributes of slurries should stimulate increased efforts to design munition systems to take advantage of the safety, performance benefits, low cost, on-site and even on-board loading capabilities.

INTRODUCTION

Our intention is to demonstrate the current usage of DBA-22M a) as an explosive fill in the BLU-82/B Helicopter Landing Zone Clearing Device, b) in cratering-type blasts for excavation without hauling the spoil by

PRECEDING PAGE BLANK

conventional means, c) in special projects for nuclear blast simulation, and d) normal commerical blasting practice.

The flexibility, portability, and safety of slurry* explosive delivery systems, coupled with the superior explosive characteristics, safety, and low cost of slurry suggests important new applications in the military field.

For example, bombs, mines, minefield clearing devices, cave destruction devices, and general demolition and/or construction quarrying blasts could all be loaded in the theatre of operation, manufacturing slurry explosives at the point of use from non-explosive ingredients.

Slurry loading systems could also be used aboard aircraft carriers to significantly decrease fire hazards and vulnerability--limiting the explosives inventory to relatively small quantities. Cook-off tests have indicated the relative safety of slurries* as compared to tritonal and other standard explosive fills.

The relative worth of having a fully qualified slurry type fill is further enhanced by low cost and high effectiveness resulting from low material costs, low labor costs, low transportation costs, low storage cost, relatively low equipment costs which means shorter lead times and lower "idling" or standby capability costs.

DBA-22M (and other similar slurries) has been well characterized and shelf life and storability are currently being proven in the field. It seems unnecessary to point out that current standard military explosive fills are not perfect in all aspects. Slurry explosives have a somewhat different set of physical, and to a lesser extent, somewhat different set of explosives properties.

The vision behind the use of slurries is not the arsenal concept where ordnance is centrally manufactured and/or stored in advance of required usage, with operating characteristics so broad as to be useful in all climates and conditions. On the contrary, it includes the manufacture in situ of customized formulations with properties which make possible the filling of empty hardware when and as needed, the elimination of live ammunition dumps with great savings in shipping, handling, and storage costs, and a corresponding reduction in the hazards involved.

CURRENT ORDNANCE APPLICATIONS FROM FIXED PLANTS

The BLU-82/B helicopter landing zone clearing device is currently being loaded by IRECO at its Site B facility 50 miles south of Salt Lake City, Utah. Figure 1 is a schematic representation of a typical slurry manufacturing pump truck.

---

* Slurries in this paper refer to slurry explosives (which contain an explosive ingredient) and slurry blasting agents (which contain no explosive ingredients).

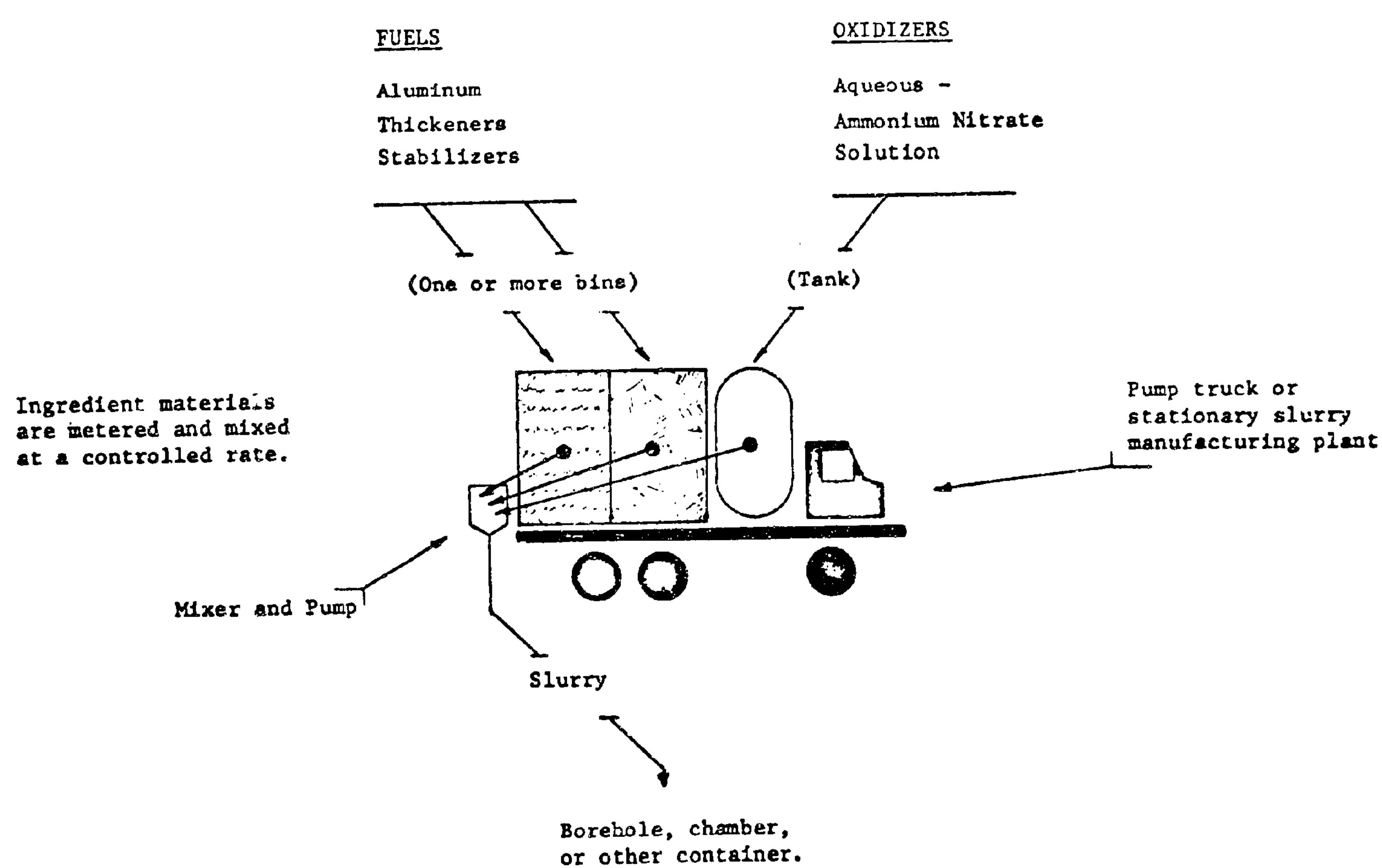

FUELS
Aluminum
Thickeners
Stabilizers
OXIDIZERS
Aqueous -
Ammonium Nitrate
Solution
(One or more bins)
(Tank)
Ingredient materials are metered and mixed at a controlled rate.
Pump truck or stationary slurry manufacturing plant.
Mixer and Pump
Slurry
Borehole, chamber, or other container.

FIGURE 1

DBA-22M slurry blasting agent is a physical mixture of non-explosive ingredients, i.e. a mixture of aluminum powder, aqueous ammonium nitrate, thickeners, stabilizers, and other proprietary ingredients. These ingredients are stored in separate compartments and tanks on the pump truck, which is the principle means by which the explosives are formulated and emplaced in remote areas. The pump truck is a mobile slurry manufacturing plant.

The Ingredient Storage Area at the Site B plant is layed out so that the powdered aluminum and other premixed fuels are received and stored in 55 gallon drums or other bulk containers on one end of the pad. On the other end of the pad dry bagged ammonium nitrate is stored on covered pallets. The aluminum and dry oxidizers are kept apart to satisfy 100 ft. separation requirements. The pump truck is loaded with dry ingredients in this area.

A small forklift is used to handle the incoming ingredient materials from the semi-trailers and is also used to load the pump truck.

A large, fiberglass tank is used to blend and store the ammonium nitrate solution. The tank is heated to keep the ammonium nitrate dissolved. The raw solution is delivered to Site B in truck tankers and is blended to final specifications in this large tank.

The solution tank is located near the Bomb Filling Area. After the pump truck is loaded with the dry ingredients at the lower Storage Area, it is driven to the Bomb Filling Area where the ammonium nitrate solution is transferred into the pump truck. Empty, unfilled BLU-82/B casings are stored in the open near the filling area.

Empty BLU-82/B bomb cases are received on flat-bed trucks and stacked ready for inspections and loading.

After inspection for shipping damage, the cases are placed in the loading revetment, as required, for filling with DBA-22M slurry.

The pump truck is driven into the reveted Filling Area and the loading hose is attached to the cases by means of fill adapter hardware. The pump truck operator initiates the slurry manufacturing process, the slurry ingredients are blended together in the proper ratio, and pumped immediately into the case.

The standard size pump truck used for this operation has the capacity to fill two of these 15,000 pound bombs (actually 12,600 pounds of slurry) before reloading with ingredient materials. While the pump truck is reloading, the BLU-82/B's are transferred by means of a large forklift from the Filling Area to the magazine Storage Area.

We reiterate that there is no explosive inventory on the truck, only non-explosive ingredients from which the slurry is blended in a continuous operation. This is not a batch type of mixing--as in a cement truck--but a continuous, metered process.

The controls and instruments of the pump truck govern and monitor the slurry manufacturing and pumping operation, and also allow the operator to have a visual check on the slurry as it is being mixed.

All standard melt cast explosive charges suffer from the problem that a void is created in the charge or bomb due to the shrinkage that occurs on solidification of the explosive fill. Slurry explosives normally suffer from a similar shrinkage that occurs during the cooling and gellation process which might also produce voids.

However, IRECO has developed a rapid bomb filling technique with slurry blasting agents which eliminates the ullage problem. This filling technique and related know-how, as well as the slurry formulation and method of manufacture, are proprietary and are protected by IRECO patents issued and pending.

Mixing and loading at rates up to 1,000 pounds/min. are attainable on a continuous basis from this type of manufacturing equipment. Loading rates of 500 pounds/min. are commonly in use in the commerical slurry explosives industry, where a three man crew employing a single unit can load up to 100,000 pounds in an eight-hour shift. The BLU-82/B's are filled at a rate of 360 pounds/min., requiring approximately only 35 minutes to fill.

Quality assurance samples are taken during manufacture, and detonation tests are run on these samples to ensure that performance specifications are met. Quality assurance tests are also performed on the ingredients before they are used to make slurry for loading into bombs.

The filled BLU-82/B's are transported to the Storage Revetment, where they receive a final inspection prior to shipment.

Because of the large size of the BLU-82/B, only two units can be carried on a semi-trailer for transport to the seaport for shipment to Southeast Asia.

In Southeast Asia the retarding parachutes are attached and the bomb and supporting cradle are rigged to a standard aerial delivery platform. The bomb on its aerial delivery platform is loaded aboard a C-130 aircraft, and the knife-cutter lines which separate the bomb from the cradle and pallet are attached. The fuze is usually installed after loading aboard the aircraft.

In the air near the target an extraction chute is deployed shortly before the drop and extracts the bomb from the C-130 upon release of the aerial delivery platform latch. The stabilization parachute opens after separation from the aircraft and retards and stabilizes the bomb on its trajectory to the target.

The bomb penetrates the follage and trees and is detonated about three feet above the ground. This standoff detonation is provided by means of a nose fuze extender. The resulting detonation creates a helicopter landing zone clearing ranging in size, with a capacity of from one to five helicopters. The heat of detonation of DBA-22M is about 1900 kcal/kgm and the loading density is 1.50 gm/cc.

Selection of slurry ingredient material provides a wide range of physical and detonation properties. Slurries can be manufactured with detonation velocities ranging from 2300 to 6500 m/sec and heats of explosion ranging from 700 to 2000 kcal/kgm. Detonation pressures of 25 to 280 kilobars are possible and slurries may be formulated with a broad range of sensitivities.

The current cost to the Government for the DBA-22M slurry fill for the BLU-82/B is approximately 28 cents per pound. This slurry cost includes the cost for handling of the GFM cases, inspections, filling with slurry, quality assurance testing, and loading and bracing on the carrier's euqipment and includes all the costs for the work performed by IRECO on the BLU-82/B bomb. These prices are representative for large quantities of high energy slurries.

MOBILE MANUFACTURING PLANTS

The foregoing demonstrates how ordnance can be loaded at a stationary plant site utilizing a mobile pump truck and a fixed equipment site, including stationary tanks, revetments, offices, and storage areas. However, IRECO has developed completely mobile support facilities to complement the mobile pump truck and they are mounted in semi-trailer vans for transport over the highways.

Currently millions of pounds of slurry blasting agents and explosives are being produced annually from such mobile support facilities at various sites in North and South America, Europe, United Kingdom, and Australia in short-term or temporary type operations where the need for mobility and cost factors preclude a fixed plant site. Such a mobile facility was used to supply DBA-22M for cratering shots of the Pre-Gondola III reservoir connection shots accomplished by the Corps of Engineers at Fort Peck, Montana.

At Fort Peck the explosives cavities were large concrete cisterns emplaced below ground level (and also below the water table). Access to these charge cavities was provided through a four-inch diameter fill pipe. These charge cavities were completely full of water at the time of slurry emplacement. Water in these cavities was not drained, and they were loaded with slurry by lowering the loading hose to the bottom of the cavity and displacing the water with slurry. This indicates the versatility and water resistance characteristics of slurries. Detonation of these charges created a linear crater which formed the connecting channel between the Fort Peck Reservoir and a previously formed basin.

Several different slurry formulations can also be manufactured and delivered by one pump truck. Extreme flexibility is possible with slurry explosives because of this mobility factor. This is illustrated by the fact that the CD-1's, prototype of the BLU-82/B, were sometimes filled while loaded on the transporting trailer.

This technique of filling on the trailer with minimized handling is very rapid, and is especially useful for filling large devices such as the BTV device

used in the AEC Readiness Program. The BTV is the largest conventional device carried or dropped by a B-52 and was dropped at Sandia's range near Tonapah, Nevada. It contained 36,000 lbs. of DBA-22M.

Bombs or other military applications, like the mining industry which we also serve, usually find their primary use in remote areas. On-site loading can be performed in these remote areas without the need for a complicated manufacturing facility.

Another example of this versatility occurred during the summer of 1969 when two different slurries, DBA-22M and DBA-XDM, were provided for the Air Force and the Defense Atomic Support Agency at their respective test sites near Cedar City, Utah. While at that location, several special bomb cases and test containers were also filled for Sandia Laboratories. These devices were never removed from the trailer, but were rapidly loaded with slurry from the pump truck and were free to continue on to their destination with a minimum of handling. This illustrates the feasibility of loading some types of ordnance in or near the theatre of operations--remembering that the ingredient materials are non-explosive.

The Air Force used the above-mentioned DBA-22M in a linear array to provide the ground shock required for a series of DI-HEST tests of missile sites. The slurry used by DASA in the Mineral Lode Event was pumped into a spherical cavity 100 feet below the ground surface.

COMPARISON WITH CONVENTIONAL MINING OPERATIONS

Slurries are presently used in mines in many countries on every continent. There is a wide variation in the size and sophistication of the pump trucks and support facilities used to support these operations. Pump trucks are available in sizes ranging from 2000 to 50,000 lb. capacities, 25,000 lbs. being the most common size, and are used to provide slurries at rugged, unimproved construction sites as well as in well-developed mines.

Most plant sites or portable operations are supported by materials transported conventionally by truck or rail car. One unique application is the method of supplying Hamersley Iron's operation in remote northwestern Australia. At that location bulk rail cars have been converted to haul the slurry ingredients--from the iron ore loading port of Dampier on the Indian Ocean, to the mine site located over 100 miles inland.

The safety of slurry is well suited to all of these types of operations.

The safety characteristics of slurries are related to physical as well as detonation properties, to the non-hazardous ingredients (usually none rated more hazardous than "oxidizer"), and the fluid phase which contributes plasticity and lessens the sensitivity to mechanical and high temperature initiation sources.

As well as the favorable cost, versatility, and safety aspects of slurry, the performance characteristics also make them useful for many ordnance applications. The results of cratering tests conducted at Tooele Army Depot in January of 1969 are given in Figure 2.

SUMMARY

The many favorable attributes of slurries should stimulate increased efforts to design munition systems to take advantage of the safety, performance benefits, low cost, on-site, and even on-board loading capabilities.

CRATERING TESTS

TOOELE ARMY DEPOT

14 January 1969

Explosive	QUANTITY/DEPTH Weight of Explosive (lbs)	Depth of Burial (ft)	RESULTS Crater Diameter (ft)	Crater Volume (CY)	Yield (CY/lb Exp)
DBA-65T2	369	8	35.0	118	0.32
DBA-22M	323	8	33.0	92	0.29
DBA-105T2	436	8	35.0	117	0.27
Minol II	373	8	31.0	85	0.23
Tritonal	386	8	30.0	82	0.21

Soil type - Silty clay with low plasticity.

FIGURE 2 Results of cratering tests of slurries and conventional melt cast explosives.

REFERENCES

Cook, M. A., "Explosives - A Survey of Technical Advances," Ind. & Eng. Chemistry, July 1968, pp. 45-55.

Hansen, G. L., "Cratering Tests of Slurry Explosives in M-117 Bombs," Intermountain Research and Engineering Co., Inc., 24 January 1969.

Moyer, John W., "Design, Development and Production of the BLU-82/B Bomb and BBU-23/B Booster," Report No. SC-DR-70-376, Sandia Laboratories, June 1970.

Thornley, G. M., "Loading DBA-XDM in Mineral Lode Event," Final Report on Contract No. 01-69-C-0169, October 1969.

Thornley, G. M., "Pre-Gondola III Reservoir Connection with DBA-22M at Ft. Peck, Montana for U. S. Army Corps of Engineers," IRECO Chemicals-Internal Report, September 1969.

The AN/Binary Explosive System for General Purpose Bombs

by L. D. Sadwin
Naval Ordnance Laboratory
Silver Spring, Maryland

Introduction

In addition to the need for an alternate explosive to the standard fills used in general purpose (GP) bombs, there exists a requirement for an explosive which can be readily prepared from readily available commercial materials. As a part of the Long Range Explosive Fills Program, the Naval Ordnance Laboratory is studying the utility of low cost, oxidizer/fuel explosives for this purpose. The output performance of such an explosive need not be as good as that of, for example H-6 or Tritonal now in use, if the new explosive demonstrates compensating advantages.

In the AN/Binary concept, it is envisioned that a sensitizing fuel is injected into oxidizer-loaded bombs during the final stages of the target delivery sequence. The system we are studying is based on using prilled ammonium nitrate (AN) as the oxidizer in combination with various fuels.

Background

The use of an oxidizer/fuel explosive in bombs is not new. I would like to quote from a patent issued in 1925[1], "Among the salient objects of the invention are to provide explosive substances which consists in combining hydrocarbons ... in a ... liquid form ... with oxidizing agents and confining them ... in a shell container equipped with an electrical igniter, fuse, or detonator". Among the oxidizing agents described in this patent is ammonium nitrate.

To quote further from the text of this patent, "An explosive made in the manner explained would have tremendous bursting power and the cost of production of such explosive material would be an important factor as explosive shells of this type could be much more economical". We are now half a century from the time that this patent application was filed. The facts have not changed.

From our earlier work with ammonium nitrate-based explosives[2,3], we know that the commercial oxidizer/fuel explosive known as AN/FO has air blast characteristics (below 100 psi) very close to that of TNT (Figure 1). In this figure, the peak overpressure for unconfined hemispheres detonated on the surface is plotted as a function of the scaled distance from the explosive. Peak pressure is very often used as a basis for comparing output performance of explosives.

For bomb performance we are often more interested in fragmentation than in blast, as fragmentation is a significant damage mechanism. In general, the higher the detonation pressure of an explosive the better its fragmentation performance. The higher the detonation energy, the better the blast. Detonation pressure and energy do not necessarily go hand-in-hand. Actual performance measurements are needed in order to characterize the blast and fragmentation performance of a particular explosive-case combination.

The AN/Binary Program

We are now completing the first phase effort in the AN/Binary program. So far, we have looked at the blast and fragmentation performance of 4 different binary mixtures. For the purposes of this paper, they are designated Binary 1, Binary 2, Binary 3, and Binary 4. These are all oxidizer/fuel explosives based on using prilled ammonium nitrate as the oxidizer.

The use of prilled ammonium nitrate as the major constituent in these explosives offers many advantages. Among these advantages

are: ready availability from existing fertilizer production plants, shipment of the AN as a non-explosive, improved safety due to the insensitive nature of the AN, and easy disposal by desensitization with water.

Along with these advantages, there are a few disadvantages. AN, being very hygroscopic, must be kept dry to avoid gassing, exudation, and like problems. Present fuze/booster components may be inadequate to initiate high order detonation in the insensitive binary explosives. Problems of compatibility between the AN and other materials in general purpose bombs as they are now produced must be solved.

Blast Performance

The peak pressure-distance behavior of the four Binary explosives we have evaluated is illustrated in Figure 2. These comparative tests were done on a constant volume basis; the weights varied from 111 lbs for Binary 1 to 153 lbs for Binary 4. The charge diameter was about 10 inches with steel confinement, so that all explosives were above their minimum critical diameter. From a blast standpoint, the decreasing order of effectiveness was found to be: Binary 3, Binary 2, Binary 4, and Binary 1.

Fragmentation Performance

Observations of fragmentation behavior were made using a flash screen method. With the aid of high-speed cameras, the average fragment velocity was measured between the explosive charge and a distance of 50 feet where the fragments impacted 0.040" thick aluminum panels. Table 1 presents the averaged fragment velocity data for the four Binary explosives tested. The average detonation velocity measured for these charges is also given in Table 1. The decreasing order of fragmentation effectiveness nearly follows the decreasing order in detonation velocity for these explosives. The order for fragmentation is: Binary 4, Binary 3, Binary 1, and Binary 2.

Summary

We have embarked on a rather ambitious program to study the feasibility of applying the AN/Binary concept in general purpose bombs. There are many engineering and safety problems that remain to be studied in future work. In this first phase we have evaluated the blast and fragmentation performance of 4 candidate mixtures. We have begun a systems analysis in order to determine how the AN/Binary concept can be incorporated with a minimum of drastic changes in the way bombs are loaded and used now. Some changes will have to be made in order to use AN/Binary explosives to their best advantage. We are very optimistic about the utility, economy, and safety advantages of this concept for general purpose bombs.

REFERENCES

1. G. Egloff, "Explosive and Process of Making Same", U.S. Patent 1,551,650, 1 Sep 1925

2. L. D. Sadwin and J. F. Pittman, "Airblast Characteristics of AN/FO, Phase I", NOLTR 69-82, 30 April 1969

3. L. D. Sadwin and M. M. Swisdak, Jr., "Blast Characteristics of 20- and 100-Ton Hemispherical AN/FO Charges, NOL Data Report", NOLTR 70-32, 17 March 1970

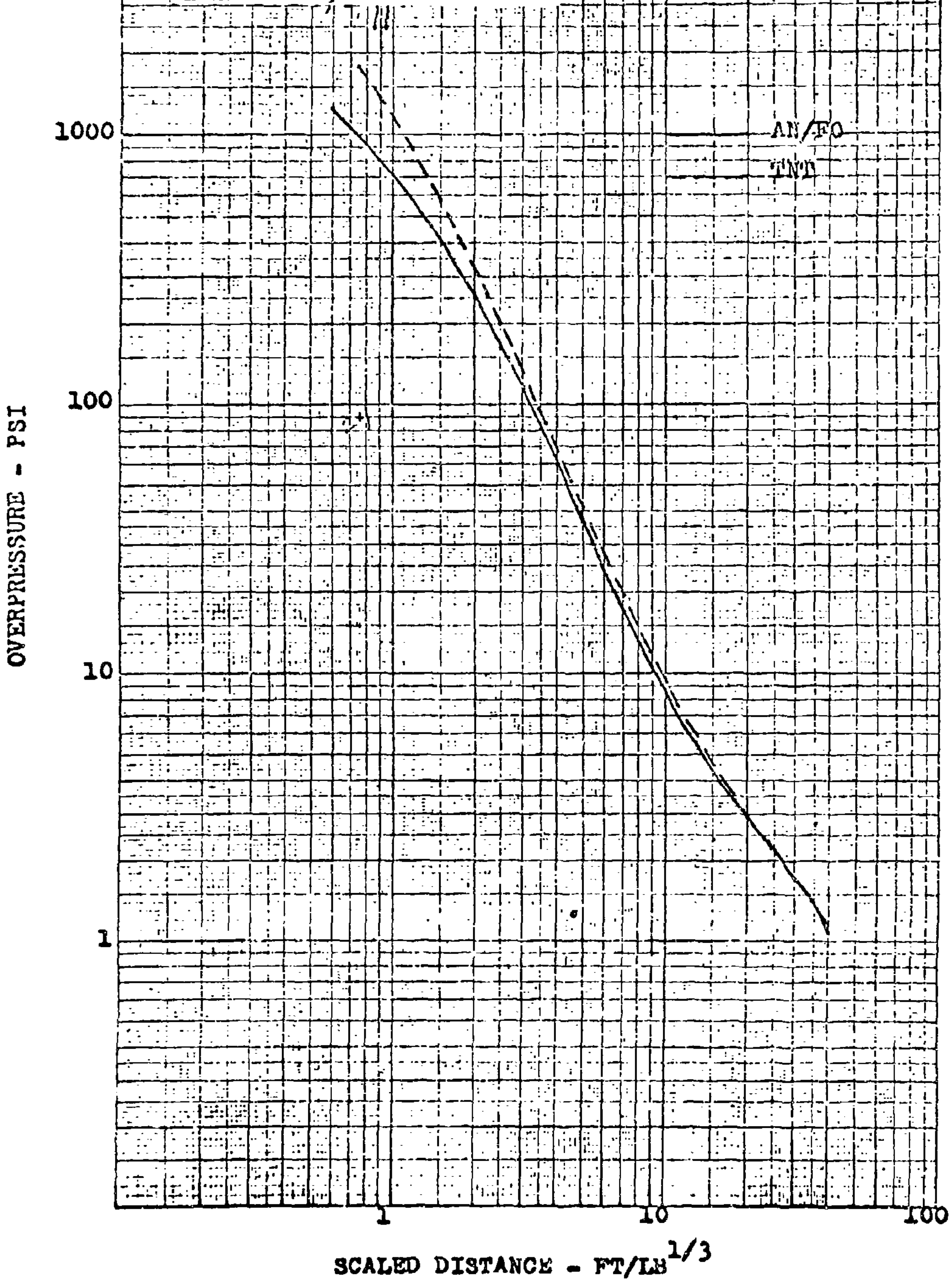
TABLE 1

AN/Binary Fragmentation and Detonation Performance

	Binary 1	Binary 2	Binary 3	Binary 4
Average Fragment Velocity Feet Per Second*	3,918	3,549	4,266	5,093
Average Detonation Velocity Feet Per Second	14,160	8,334	10,140	19,770

* Averaged Between Charge and Flash Panels at 50 feet

Figure 1. Composite of Pressure - Distance Data for hemispherical AN/FO and TNT at the Defence Research Establishment, Suffield



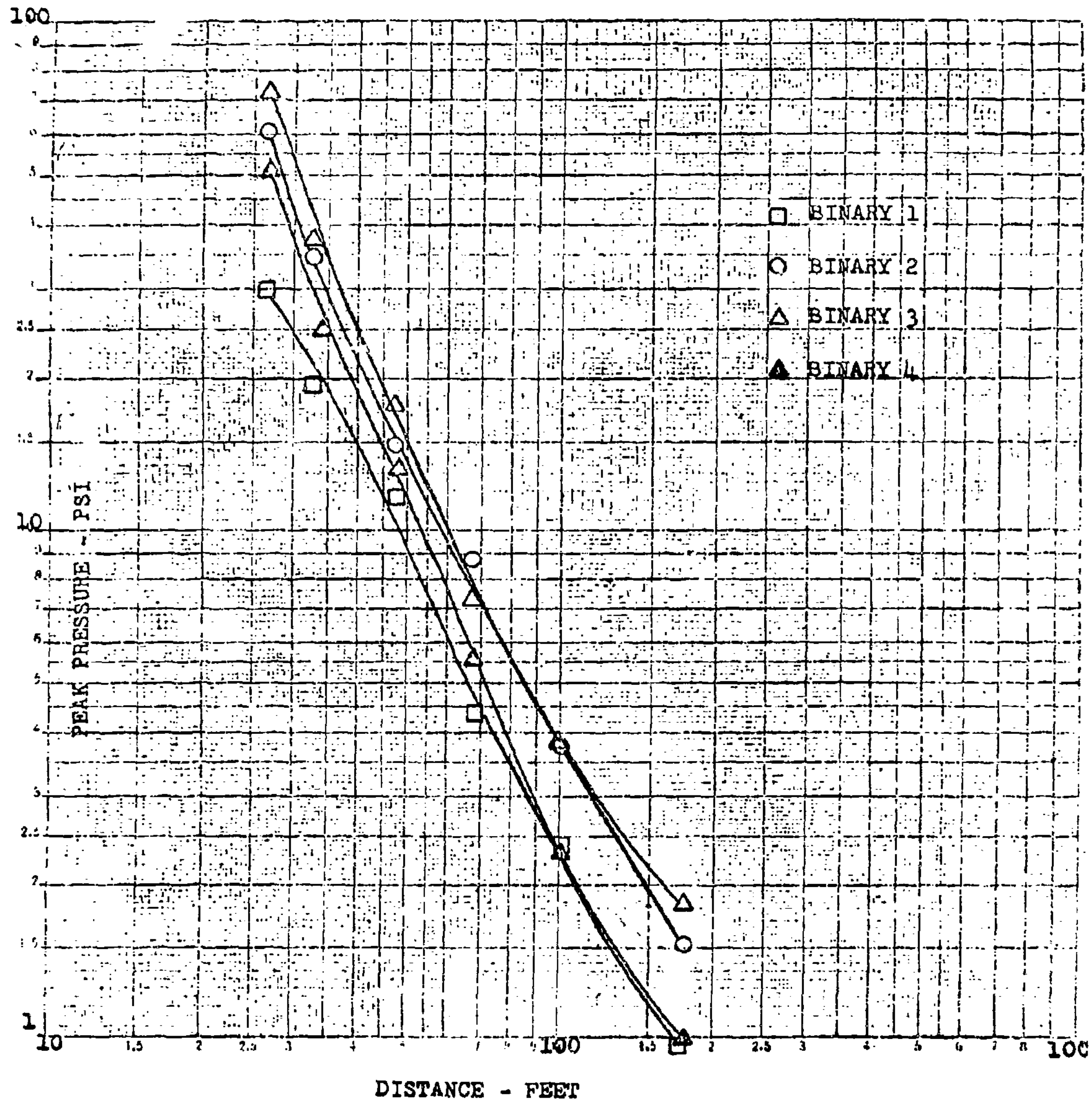


FIGURE 2 PEAK AIRBLAST PRESSURE VERSUS DISTANCE FOR AN/ BINARY EXPLOSIVES.

Watch Your Equivalent Weight
Part II--Pressure Vessels

by Joseph Petes
Naval Ordnance Laboratory
Silver Spring, Maryland

Last year at the Twelfth Explosive Safety Seminar sponsored by the ASESB, I presented a paper on Equivalent Weights--its uses and misuses. Guidelines were suggested for the proper way to compare explosives or explosion effects. It was pointed out that in order to make valid and meaningful comparisons between the explosion of interest and some standard explosion, it is necessary to consider similar shapes, geometries, and spectra of effects for the two explosions. And as a concluding thought, I added that if for some reason these guidelines could not be observed, at least the basis for the standard of comparison should be indicated so that the user of the comparative figure or the equivalent weight determination would have some means of evaluating this finding (Ref. (1)).

What I said last year still has merit, but I would like to change the pitch a bit this year. Why compare explosions in terms of equivalent weights when the equivalent weight comparison can becloud the issue? I could have, perhaps, should have made this pitch last year when the TNT equivalence of rocket propellant and ammunition storage explosions were discussed, but precedence and common usage die hard. Today, however, I make the pitch and use rupturing pressure vessels as the illustrative example. It just doesn't make sense in many cases to talk about TNT equivalence of a rupturing pressure vessel; the physics of a rupturing vessel is different from that of a TNT explosion and the results are different. What we really are interested in is the damage potential of this vessel.

Over the years, several studies have been made of the blast effects of rupturing pressure vessels. Some investigators did a numerical evaluation (Ref. (2)), others, laboratory experiments (Ref. (3)), and still others, analysis of rocket motor tankage (Ref. (4)). As a matter of fact, at the Ninth Explosive Safety Seminar, Boudreaux presented an excellent paper on "TNT Equivalence--Gas Dynamics Comparison for Moderately Pressurized Tanks" (Ref. (5)). Note the title--TNT Equivalence. Why TNT Equivalence, I ask now, when the painstaking analysis he made indicates that a rupturing moderately pressurized tank produces a pressure-distance curve which is very unlike a TNT pressure-distance curve? Superimposed on the family of TNT pressure-distance curves in Figure 1, Boudreaux has his predictions for the pressure-distance for a rupturing horizontal pressurized cylinder. Only in a very limited range is there a correspondence between some equivalent TNT curve and the pressure-vessel curve. If I were a safety engineer or a design engineer, I don't think it would help me much to know that between 0.1 psi and 2 psi the rupturing cylinder acts like 185 lbs of TNT, but at 30 psi it acts like 25 lbs of TNT. I think I would be perfectly happy to have the predicted pressure-distance curve for the rupturing cylindrical tank unfettered and uncluttered by TNT equivalence. And I think I would want information of the fragmentation pattern of this tank; large, high velocity fragments may cause more damage than the blast.

In all fairness to Boudreaux and with due respect for the excellent blast analyses he did, I must say that despite the title of his paper, he does not make an issue of TNT equivalence. But I am afraid some of us may and do.

It's so easy to keep on talking of TNT equivalence of explosion effects even when it has no real physical foundation. Just recently while in the midst of preparing this paper, I saw an article in the newspaper reporting on an explosion at Roosevelt Raceway in New York (Ref. (6)). A soda machine blew up, or more accurately, a compressed gas cylinder in the machine exploded. Twenty-three persons were injured. The momentary thought that occurred to me was "What was

the TNT equivalence of this soda pop machine pop with twenty-three hurt?". But the thought was only momentary; the twenty-three sustained their injuries not directly from the exploding machine but from stampeding towards the exits in panic when they heard the explosion. So, this soda machine explosion equivalence fizzled.

As amusing as this accounting of the story may be, it does illustrate my point: where there is little basis for comparison, don't make comparisons. All explosions are not the same. Certainly the explosions of TNT and a pressure vessel are grossly different both in their basic physics and in their effects. Just as a review, let us look briefly at the details of a rupturing high pressure vessel and at the explosion of a TNT charge. Observing my own admonition calling for similarity of shape, geometry, and spectra of effects, consider the pressure vessel and the TNT charge both to be spherical, in free air (that is, there is no ground or other surface perturbing the effects), and we look at the blast from high pressure levels to low.

When the TNT charge is detonated, much goes on within the charge which is not immediately evident as blast outside the charge. A high velocity, high pressure wave is generated within the explosive with detonation velocities of about 7050m per sec and detonation pressures of about 180 kbar or over two million psi. Upon reaching the surface of the charge, this detonation results in an air shock wave with a pressure of about 8,000 psi just outside the original surface of the charge. As the blast expands radially away from the source, the pressure magnitude drops; we can describe this with the familiar pressure-distance curve.

Now consider a pressurized vessel. Just prior to the rupture of the vessel there is no action, no high velocity, high pressure detonation wave within the vessel. When the vessel ruptures there is an immediate release and expansion of the contained gases. In short time, the expanding gas through a marvelous process too detailed to cover here, "shocks up", producing a true shock wave or airblast wave. (This is analagous to the classical spherical shock tube.)

The blast wave in the process of expanding away from its source decays in amplitude in a fashion similar but not identical to the TNT blast wave. And so, a pressure-distance curve can be drawn for the rupturing spherical vessel.

But the TNT curve and the pressure vessel blast curves are different. No matter how large or small the TNT charge, the starting airblast shock pressure is the same, 8,000 psi. For the pressure vessel, the starting air shock pressure is a function of the contained gas pressure at the time of rupture, and it's a relatively small fraction of this. For most practical situations of concern with pressure vessels or tanks holding up to perhaps thousands of psi of gases, upon rupture of these vessels there are only hundreds of psi of airblast--a far cry from the 8,000 psi of TNT explosions.

Let us look at a specific example to illustrate these differences. Consider a spherical pressure vessel containing 6 cu ft of air initially at 8,000 psi and 15°C. If we suddenly and uniformly release this pressure, that is ideally fragment the tank, we have a spherical shock tube situation. We can calculate the initial shock pressure using the following equation (7)).

$$\frac{p_4}{p_1} = \frac{p_2}{p_1}\left[1 - \frac{(\gamma_4 - 1)(a_1/a_4)(p_2/p_1 - 1)}{\sqrt{2\gamma_1}\sqrt{2\gamma_1 + (\gamma_1 + 1)(p_2/p_1 - 1)}}\right]^{-2\gamma_4/(\gamma_4 - 1)}$$

where p_4 = driver pressure (absolute)
p_1 = ambient pressure (absolute)
p_2 = resulting shock pressure (absolute)

γ_4 = driver gas specific heat ratio
γ_1 = ambient gas specific heat ratio

a_4 = sound speed in driver gas
a_1 = sound speed in ambient gas

This gives us an air shock pressure of about 130 psi at or close to the rupturing sphere. Obviously this is far removed from the initial static 8,000 psi in the pressure vessel; and it's equally far from the initial pressure obtained from a TNT explosion.

But, you may say, I made an unfair comparison. I should compare the airblast from equivalent energy sources at the same distance. Okay, let's do that.

There are various ways to calculate the potential energy of the pressurized sphere. Without going into the details, for our example, we come up with a figure of 46.7×10^5 calories. Using the familiar 1018 cal per gram for TNT, and dividing the former by the latter we find that the 6 cu ft pressurized sphere at 8,000 psi has an energy equivalent to 4.59×10^3 grams or 10.1 lbs of TNT. Now we draw a pressure-distance curve for 10.1 lbs of TNT detonated in free air. Figure 2 shows this curve from the charge surface out to 1 psi. And on this Figure we also have the shock pressure we calculated for the rupturing 8,000 psi sphere using the shock tube equation. So let's compare pressures from the equal energy sources and at the same distance, right at the radius of the pressurized sphere; there is more than an order of magnitude difference. There is just no way to make the blast from a rupturing pressure vessel look like a TNT explosion at the start.

Since the purpose of this paper is not to give details of how we predict pressure-distance relationships for bursting vessels, Figure 2 simply shows this prediction. (The references give adequate treatment of the methodology.) And we see that even further out, at low pressures, the rupturing vessel curve does not follow the TNT equivalent energy curve; it crosses over, in our example, at 10 psi.

Why am I so adamant in saying that a rupturing sphere is not like a TNT explosion? Well, for one, it just isn't as these pressure-distance curves show. Even though the two explosions have the

same initial energy, the release of this energy and the formation of the airshock are totally different in the two situations giving rise to totally different initial conditions. Eventually at some distance, the pressure vessel p-d shock looks like a TNT p-d curve, but this degree of similarity is hardly sufficient, in my estimation, to say that the pressure vessel has a TNT equivalence of 10.1 lbs in this example. As sure as death and taxes, someone is going to use this TNT equivalence figure, draw a TNT pressure-distance curve for 10.1 lbs of TNT, and say that that is what will result from a rupturing vessel. What's wrong with this? Far out, it's not conservative nor safe; close-in, it's expensive and may negate some systems.

Consider a pressurized tank adjacent to a building wall, or attached to a space capsule, or within a soda machine. If the TNT equivalence attained at the low airblast pressures is used to design for the high airblast pressures, and safety is the concern, the wall may have to be extra thick and extra reenforced, the space capsule clad in thick steel, and the soda machine contained in a Sherman tank. I don't think this is done, and, of course, it shouldn't be done. I would like to think that we are observing correct design procedures. And yet, I have the uneasy feeling based on years of observation and questions asked us, that safety design with respect to what is in the near vicinity of the pressure vessel is largely ignored. This need not be. Good information is available on the blast effects of rupturing vessels. The correct information is the simple pressure-distance prediction for a rupturing pressure vessel--without reference to its TNT blast or energy equivalence.

I've talked at length about blast differences between TNT explosions and rupturing vessels. I made a gross simplification about the rupturing vessel: I assumed it would break uniformly, releasing its gases in a spherical expansion, and that the ensuing blast would be spherically symmetrical. I believe this to be a gross oversimplification and not likely to occur in most real situations. The vessel will rupture at some weak point, propagate cracks, and depending on the ductility of the case, peel back or

fracture into large pieces. Close in to the vessel, the contained gas will be jetting out in finger-like projections producing gross asymmetries in the blast pattern. Depending on the type and rapidity of the fractures, the vessel or large portions of it, will take off like a rocket. These too, the fragments and large vessel parts, have to be considered in terms of damage potential and safety.

Frankly, I don't know how to predict the fracture pattern of a rupturing vessel; there are just too many variables and undeterminables in the vessel construction, material properties, and points of stress. But I dare say that this pattern is different from that which results when a TNT spherical bomb explodes. The detonation pressures pretty uniformly stress and fracture the case producing many small high velocity fragments. So again, as with the airblast pressures, there are marked differences between a rupturing TNT cased charge and a rupturing vessel when the fragments are considered. And there is no real meaningful equivalence.

Last year, I said I was on a soap box proposing a meaningful use of equivalent weights. As you see, I'm still on that soap box. Now I am saying, don't use equivalent weight as a short cut to describing what happens when a pressure vessel ruptures. Talk about the damage potential of the vessel in terms of its predicted or measured blast and fragment characteristics. This will lead to less confusion in the field and hence, safer and less costly design. After all, that's what this seminar is all about.

30 August 1971

REFERENCES

1. Minutes of the Twelfth Explosives Safety Seminar prepared by Armed Services Explosives Safety Board, Washington, D.C., pp. 371-380, 25-27 Aug 1970

2. Brode, H.L., "Numerical Solution of Spherical Blast Waves", J. Appl. Phys., 26, 766 (1955)

3. Boyer, D. W., Brode, H.L., Glass, I.I., and Hall, J. G., "Blast from a Pressurized Sphere", Univ. of Toronto, Institute of Aerophysics Rpt No. 48, Jan 1958

4. Moskowitz, H., "Blast Effects Resulting from Fragmentation of an Atlas Missile", Vol. 3, No. 5, AIAA Journal of Spacecraft and Rockets (May 1966)

5. Minutes of the Ninth Explosives Safety Seminar prepared by Armed Services Explosives Safety Board, Washington, D. C., pp. 183-198, 15-17 August 1967

6. Item in the Washington Post, 24 August 1971

7. Liepmann, H. W. and Roshko, A., "Elements of Gasdynamics" p. 81, (Wiley N.Y. 1957)

8. The pressure-distance curves presented in this paper are predictions made by D. Lehto, Naval Ordnance Laboratory, Silver Spring, Maryland

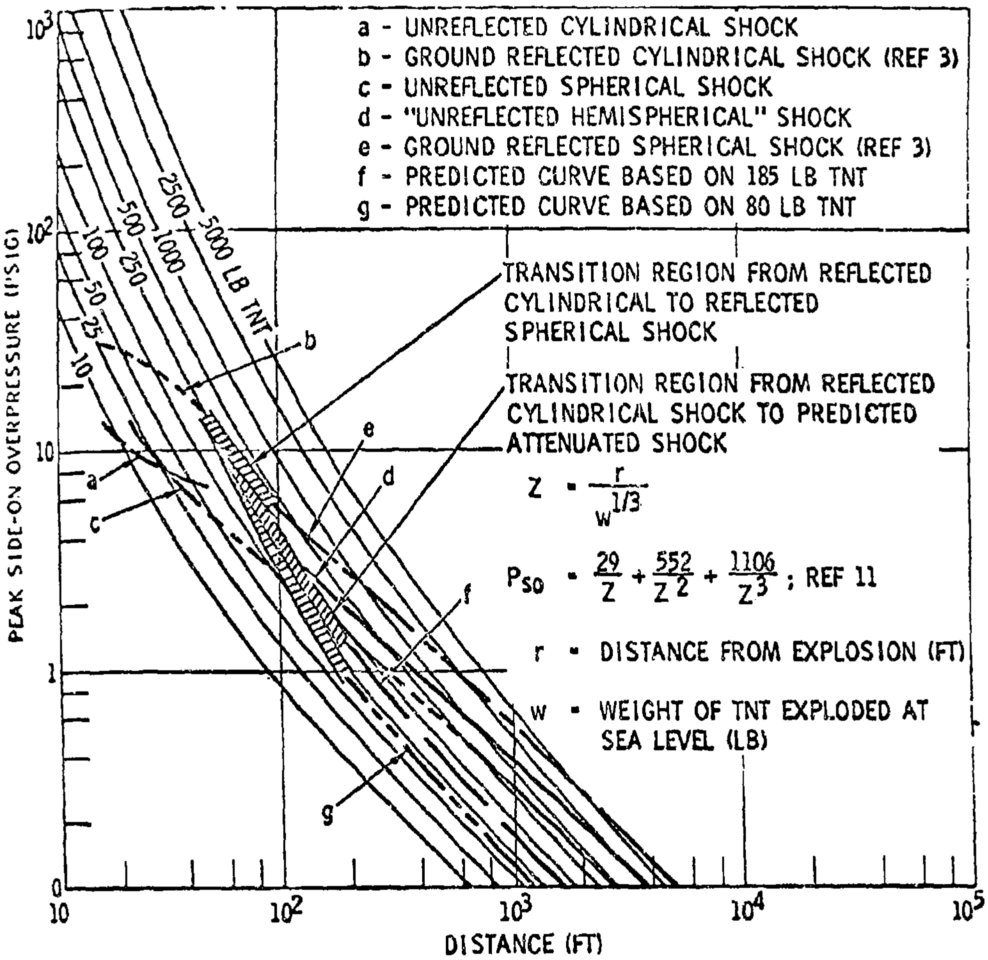


Figure 1 Peak Side-On Ground Blast Pressure as a Function of Distance and Weight of Explosive; Variable Area Shock Tube Analogy Results Superimposed

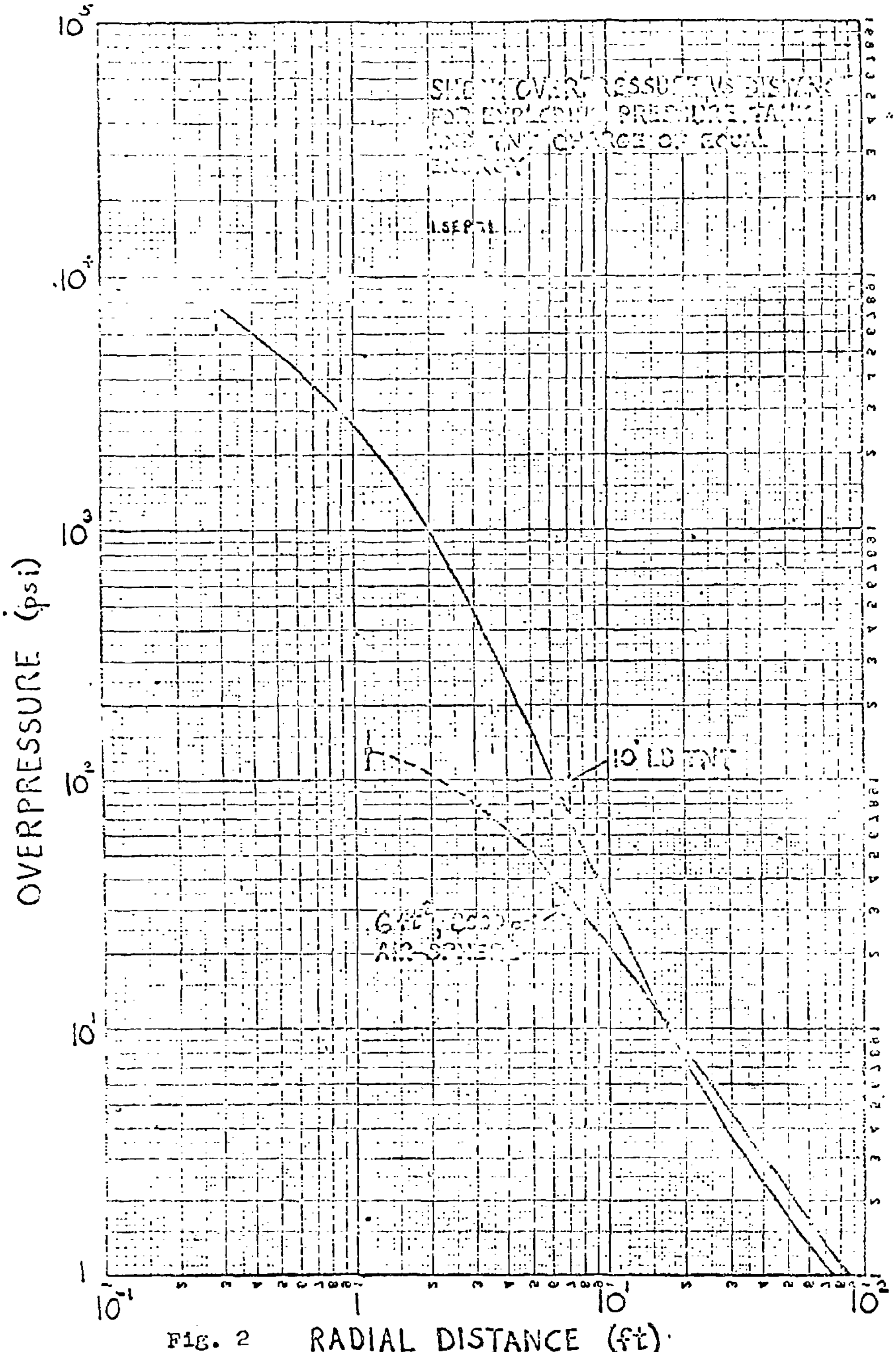

10^5
10^4
10^3
10^2
10^1
1
OVERPRESSURE (psi)
10^{-1}
1
10^1
10^2
RADIAL DISTANCE (ft)

Fig. 2

Sept. 1971

ADMINISTRATION OF THE SAFETY ASPECTS OF CONTRACTS
IN CONTRACTOR-OPERATED FACILITIES

By
Mr. H. L. Deans, Safety Engineer; Chief, Program Evaluation
US Army Materiel Command

MR. CHAIRMAN - GENTLEMEN:

THE OBJECTIVE OF THIS DISCUSSION IS TO PROVIDE A BETTER UNDERSTANDING BETWEEN GOVERNMENT AND INDUSTRY IN REGARD TO CONTRACTUAL SAFETY OBLIGATIONS. IT IS TO BE ADDRESSED FROM A VIEWPOINT OF YESTERDAY, TODAY, AND TOMORROW.

HISTORICALLY, IT MAY BE SAID THAT THE ARMY WAS THE FORERUNNER IN PROCUREMENT SAFETY MATTERS. THIS, IN ITSELF, CAN ONLY BE CONSIDERED LOGICAL SINCE, FOR YEARS, THE ARMY HAS PROCURED AND MANUFACTURED THE MAJORITY OF THE AMMUNITION, EXPLOSIVES, AND AMMUNITION COMPONENTS USED THROUGHOUT THE DEPARTMENT OF DEFENSE. WE MAY GO FURTHER AND SAY THAT THE REAL INCREASE IN PRE- AND POST-AWARD SAFETY SURVEYS HAD ITS BEGINNING DURING THE POST KOREAN CONFLICT ERA OF THE 1950'S.

DURING THIS PERIOD, IN FACT THRU 1961, SAFETY SURVEYS OF PRIVATE CONTRACTOR FACILITIES WERE PERFORMED ON A SEMIANNUAL BASIS BY THE ORDNANCE FIELD SAFETY OFFICE (CURRENTLY USAMC FIELD SAFETY AGENCY), CHARLESTOWN, INDIANA. THIS EFFORT WAS OPERATED UNDER GUIDELINES INITIATED BY ARMY EXPLOSIVES SAFETY PROFESSIONALS SUCH AS JACK BATLEY (DECEASED), FRED BISHOFF (CURRENTLY WITH DEPARTMENT OF LABOR), HARRY GUEST (RETIRED), AND HARRY BRINKLEY (ALSO RETIRED), ALL OF WHOM ARE KNOWN TO MANY ATTENDEES OF THIS SEMINAR. I WAS FORTUNATE AND PRIVILEGED TO BE A MEMBER OF THAT TEAM. THIS WAS A PERIOD IN WHICH MANAGEMENT BECAME MORE AWARE OF THE NEED FOR SAFETY IN THE PROCUREMENT

OF HAZARDOUS MATERIALS. REASONS FOR SUPPORTING INCREASED FREQUENCY IN PRE- AND POST-AWARD SAFETY SURVEYS WERE APPARENT BUT NOT NECESSARILY LIMITED TO EFFORTS DESIGNED FOR:

a. CLOSER COORDINATION OF ALL SAFETY MATTERS BETWEEN ARMY AND PRIVATE CONTRACTORS.

b. DETECTION AND DEFINITION OF POTENTIAL AND ACTUAL HAZARDS SUPPORTED BY CONSTRUCTIVE RECOMMENDED ACTIONS.

c. REDUCTION OF ADVERSE PUBLIC CRITICISM WHICH GENERALLY FOLLOWS SERIOUS INCIDENTS OCCURRING IN SUCH PLANTS.

d. PROMULGATION OF EXPLOSIVES SAFETY STANDARDS ACCEPTABLE TO BOTH GOVERNMENT AND INDUSTRY.

e. REDUCTION OF LITIGATION ARISING FROM DISABLING INJURIES AND FATALITIES OCCURRING IN PLANTS UNDER ARMY CONTRACTS.

f. INCORPORATION OF LOGICAL ACCIDENT PREVENTION MEASURES WITH EMPHASIS DIRECTED TOWARD REDUCTION IN ACCIDENTAL LOSSES OF LIFE, LIMB, AND PROPERTY.

IN 1962, THE ARMY WAS FACED WITH A REORGANIZATION WHICH COMBINED THE US ARMY "TECHNICAL SERVICES" (CHEMICAL, ORDNANCE, ETC.). SHORTLY FOLLOWING WAS THE ESTABLISHMENT OF THE DEFENSE CONTRACT ADMINISTRATIVE SERVICES UNDER THE DEFENSE SUPPLY AGENCY. BASICALLY, DCAS WAS RESPONSIBLE TO ADMINISTER CONTRACTS FOR THE MILITARY SERVICES (ARMY - NAVY - AIR FORCE). A DOD WORK GROUP WAS ESTABLISHED TO DEVELOP AN EXPLOSIVES SAFETY STANDARD ACCEPTABLE TO THE THREE MILITARY SERVICES. THIS STANDARD WAS TO INCORPORATE THOSE STANDARDS CONSIDERED MINIMAL FOR SAFE AND EFFICIENT OPERATIONS. ALSO, IT WAS TO PRESENT A "SINGLE

FACE" TO INDUSTRY TO CIRCUMVENT CONTRACTOR COMPLIANCE WITH MULTIPLE AND IN SOME CASES CONFLICTING STANDARDS PROMULGATED BY THE VARIOUS MILITARY SERVICES. THUS, THE OBJECTIVE WAS TO ESTABLISH A SINGLE REFERENCE FOR CONTRACTOR COMPLIANCE. THIS BECAME A REALITY IN OCTOBER 1968 WHEN THE DOD CONTRACTORS' SAFETY MANUAL WAS PUBLISHED. CONTRARY TO SOME WELL MEANING RUMORS, THE DRAFT MANUAL WAS COORDINATED WITH INDUSTRY, NAMELY - CODSIA. SOME PROBLEMS WERE STILL UNANSWERED AND THIS LEADS TO OUR PRESENT POSITION OF INTERPRETATION AND CLARIFICATION OF EXISTING PROBLEMS REGARDING THE DOD MANUAL.

CURRENTLY, THE MATTER OF ADMINISTERING AND MANAGING THE DOD MANUAL CONTINUES TO POSE QUESTIONS OF INTERPRETATION. IT MUST BE RECOGNIZED THAT THE PUBLICATION OF THIS DOCUMENT WAS NOT AN EASY TASK. DIFFICULTY WAS EXPERIENCED IN MANY AREAS OF CONCERN: 1. PRESCRIBING STANDARDS (MANAGERIAL AND OPERATIONAL) WHICH ENCOMPASSED BOTH THE GOVERNMENT-OWNED AND CONTRACTOR-OPERATED (GOCO) FACILITY AND THE CONTRACTOR-OWNED AND CONTRACTOR-OPERATED (COCO) FACILITY. THE LATTER IS OFTEN SPOKEN OF AS PRIVATELY-OWNED AND PRIVATELY-OPERATED (POPO); 2. ESTABLISHING STANDARDS WHICH GOVERN BOTH THE RESEARCH AND DEVELOPMENT CONTRACTS AND THE PRODUCTION CONTRACTS; 3. DEVELOPING STANDARDS, THE TERMINOLOGY OF WHICH COULD BE INTERPRETED BETWEEN MILITARY DEPARTMENTS AS WELL AS BETWEEN GOVERNMENT AND CONTRACTOR PERSONNEL.

A MORE RECENT INQUIRY REFLECTS THIS PARTICULAR ISSUE. IT INVOLVED PERSONNEL OF THE ARMY, DCAS, AND CONTRACTOR, AND WAS CENTERED ON THE STANDARD APPLICABLE TO THE LOCATION OF ELECTRICAL CONTROLS FOR AN EXPLOSIVES GRINDING OPERATION, INVOLVING OXIDIZER MATERIALS. SUCH

CONTROLS ARE TO BE POSITIONED AT BARRICADED INTRALINE DISTANCE BASED ON THE QUANTITY AND TYPE OF EXPLOSIVES INVOLVED. IN THIS PARTICULAR CASE, A RESEARCH GRINDER OF ONE GALLON (LABORATORY) CAPACITY WAS LOCATED ADJACENT TO A REINFORCED CONCRETE WALL WITH THE CONTROLS FOR THE GRINDER ON THE OPPOSITE SIDE OF THE WALL. SINCE THE PRIMARY CONSIDERATION IS TO AFFORD COMPLETE PERSONNEL PROTECTION, THE INTENT OF THE REQUIRED STANDARD WAS MET, AND ALTHOUGH REPORTED AS A SAFETY DEFICIENCY, THE PROCURING CONTRACTING OFFICER (PCO) ACCEPTED THIS CONDITION. NATURALLY, IF THE GRINDER WAS A LARGE PRODUCTION OPERATION, THE PCO WOULD NOT HAVE ACCEPTED THE CONDITION. IT IS TO BE NOTED THAT THIS WAS NOT A WAIVER OR EXEMPTION ACTION, BUT MERELY AN ACCEPTANCE OF EXISTING OPERATING FACILITIES AS AUTHORIZED BY PARAGRAPH 104b, DOD 4145.26M.

ANOTHER CASE OF ISSUE INVOLVED THE INHABITED BUILDING QUANTITY-DISTANCE SEPARATION STANDARD. THE BOUNDARY LINE OF A PLANT IS PRESCRIBED AS THAT POINT WHERE EXPLOSIVES FACILITIES MUST BE GOVERNED BY THE IHB DISTANCE. IN THIS CASE, SEVERAL EXPLOSIVES STORAGE MAGAZINES WERE LOCATED APPROXIMATELY SIX FEET FROM THE PRIVATE PLANT'S BOUNDARY LINE FENCE. PRESCRIBED DISTANCE SEPARATION WAS VIOLATED. HOWEVER, THE AREA ON THE OPPOSITE SIDE OF THE FENCE WAS MARSHLAND EXTENDING TO A HILL, THE CLOSEST HOME OR PUBLIC FACILITY BEING AT A DISTANCE OF SEVERAL THOUSAND FEET. THE PCO ACCEPTED THIS CONDITION, <u>PROVIDED</u> THERE WAS NO PUBLIC ENCROACHMENT BETWEEN THE HILL AREA AND THE BOUNDARY FENCE. THUS, STORAGE OF CERTAIN QUANTITIES AND CLASSES OF EXPLOSIVES WAS PERMITTED IN THE EXISTING MAGAZINES.

FROM THE FOREGOING, IT IS APPARENT THAT EACH ISSUE INVOLVING CONTRACTOR NONCOMPLIANCE WITH SAFETY STANDARDS MUST BE EVALUATED ON ITS INDIVIDUAL MERIT. THUS, IT IS INCUMBENT UPON THE DCAS ADMINISTRATING CONTRACTING OFFICER (ACO) TO PRESENT COMPLETE DETAILS TO THE PCO IN ORDER THAT CONSTRUCTIVE RESOLUTION OF THE ISSUE MAY BE MADE. CONTRACTORS SHOULD NOT BE DETERMINED NONRESPONSIVE AND CONTRACTS SHOULD NOT BE DENIED UNDER NONCOMPLIANCE WITH APPLICABLE SAFETY STANDARDS WHEN DETECTED AND REPORTED DURING PRE-AWARD SURVEY WITHOUT THOROUGH EVALUATION OF EXISTING CONDITIONS BY THE PCO. ADDITIONALLY, ASSISTING THE CONTRACTOR IN CORRECTION OF REPORTED UNSAFE CONDITIONS IS OF UTMOST IMPORTANCE. CURRENT STANDARDS REQUIRE THAT THE CONTRACTOR BE NOTIFIED AND GIVEN THE OPPORTUNITY TO CORRECT SUCH CONDITIONS.

"FUTURE" IS A WORD THAT, IN OUR PRESENT STATE OF AFFAIRS, CONTAINS MANY MYSTIC CONNOTATIONS. HOWEVER, IT IS NO MYSTERY THAT SAFETY PROFESSIONALS MUST UPGRADE THEIR PAST AND PRESENT EFFORTS. THIS IS NOT IMPLIED AS ANY FORM OF CRITICISM TOWARD THE ASPR SAFETY CLAUSES, THE DOD CONTRACTORS' SAFETY MANUAL, THE DATA ITEM DESCRIPTIONS FOR CONTRACTUAL USE, OR THE EFFORTS OF ANY PARTICULAR INDIVIDUALS OR AGENCIES. SAFETY TODAY PRESENTS A CHALLENGE FOR THE FUTURE. ALTHOUGH OUR STATISTICAL ACCIDENT RECORDS HAVE IMPROVED THROUGH THE YEARS, ADDITIONAL MEASURES, IN OUR ENVIRONMENTAL CONSCIOUS SOCIETY OF TODAY, MUST BE INCORPORATED THROUGH SAFETY PROFESSIONALISM. CURRENT LITIGATION UNDER THE TORTE CLAIMS ACT DEMANDS CONTINUED AND IMPROVED SAFETY FOR BOTH GOVERNMENT AND INDUSTRY. TECHNOLOGICAL ADVANCEMENT IN THE WORLD TODAY WILL, MOST CERTAINLY, NOT SLOW OR DETER ITS MOVEMENT WHILE

AWAITING INCREASED FORETHOUGHT, IMPROVED TRAINING, AND NECESSARY ACTION ON THE PART OF SAFETY PROFESSIONALS.

IF THERE WERE BUT ONE REFERENCE OR CONGRESSIONAL ACTION TO BE QUOTED AS THE "MAIN SPRING" IN UPGRADING THE POSITION OF THE DOD CONTRACTORS' SAFETY MANUAL, IT WOULD HAVE TO BE THE MORE RECENT OCCUPATIONAL SAFETY AND HEALTH ACT. WHILE THE DOD MANUAL WAS GEARED TOWARD MINIMAL EXPLOSIVES SAFETY STANDARDS, THE NEW "ACT" IS MORE DETAILED IN INDUSTRIAL SAFETY STANDARDS. IT WILL REQUIRE STATE LEGISLATION WHICH, IN SOME CASES, IS BASICALLY CONSIDERED INADEQUATE. INSPECTION AND ENFORCEMENT WILL IMPROVE THE OVERALL POSTURE OF PLANT FACILITIES AND OPERATIONS. IN TURN, CONTRACTORS WILL BE DETERMINED MORE RESPONSIVE. RECOGNIZING THAT THIS ENHANCEMENT IS DEPARTMENT OF LABOR ORIENTED, DOD IS NOW FACED WITH REVISION OF THE DOD CONTRACTORS' SAFETY MANUAL AND CLOSER COORDINATION WITH THE DEPARTMENT OF LABOR, HEW, AND INDUSTRY. IN THIS RESPECT, CHANGING OF THE QUANTITY-DISTANCE TABLES IN THE DOD MANUAL IS BUT ONE OF THE MANY ANTICIPATED IMPROVEMENTS. OUR PAST OBJECTIVES MUST BE RE-EVALUATED, CHANGED WHERE NECESSARY, AND UPGRADED TO MEET FUTURE MISSION REQUIREMENTS.

ADMINISTRATION OF THE SAFETY ASPECTS OF CONTRACTS IN CONTRACTOR OPERATED FACILITIES

by

John D. Komes
Defense Contract Administration Services

Back in August of 1966 at the Eighth Explosive Safety Seminar that was held at Huntsville, Alabama, there was a presentation entitled, "The Role of DCAS in the Administration of Safety in Contractor Plants". The presentation was given by Mr. Hy Ackerman, then the Chief Safety Engineer for DCAS. As most of you know, Hy died a few years ago, but the single department of Defense safety standard that he envisioned and discussed at that Seminar is now a reality. The Department of Defense Contractors Safety Manual for Ammunition, Explosives and Related Dangerous Material (DoD 4145.26M) was published in October 1968.

A short time later, Armed Services Procurement Regulation 7-104.79 was issued, this ASPR was and still is the basic instruction that implements the DoD Manual.

At that point in time we entered a new era in explosive safety. For the first time a Defense contractor had one explosive safety standard.

Prior to the DoD Safety Manual, Defense contracts contained a variety of advisory safety standards. Not to mention the fact that the Services were also in the field conducting surveys using these different standards.

I remember one contractor back in St. Louis who was visited by Government safety representatives from four different procurement activities during a two month period.

It was this type of activity that prompted the development of Defense Contract Administration Services (DCAS). This established a "One Face to Industry" concept.

Explosive safety was included as part of the DCAS responsibility.

So much for ancient history.

Today all of our Defense contracts for ammunition explosives and related dangerous material contain mandatory explosive safety standards. The recent implementation of the Occupational Safety and Health Act by the U. S. Department of Labor, which replaces the old Walsh-Healey Act, is on the street and it

looks like we will all be seeing a lot of activity in that area. Not to mention the recent implementation of the "Organized Crime Control Act of 1970", by the U. S. Department of Treasury.

This Act, in addition to its physical security requirements, contains specific safety standards. So with this background, I'll move into our topic area.

Currently DCAS safety personnel are administering the safety aspects of approximately 90-95% of Department of Defense contracts for munitions. This is a large undertaking as it covers almost all of the 50 states and some territories. With this large volume of work, a few problems seem to crop up from time to time. In most cases these problems are concerned with the implementation of the DoD Contractor Safety Manual, either during a preaward survey or a post award survey.

With this in mind, I will review the procedure established by the DoD Manual for evaluating a contractor's facility.

When one of the Services decides it needs a munitions item, normally an IFB (Invitation For Bid) is issued. At this point in time your sales and technical people put a bid together. However, in some cases it is not realized that the IFB contains ASPR Clause 7-104.79. This sometimes leads to a very unhappy ending. But let us assume that your company is the low bidder and is prepared to perform the work. Normally the next step is the preaward survey, which is when the Government examines your ability to perform the work in accordance with the terms of the bid package, which by the way includes mandatory safety standards.

It never ceases to amaze me when, during the preaward surveys, some contractors suddenly realize that we really intend to assure compliance with these standards. But the real shock occurs if the contract is not awarded due to safety deficiencies. Yes, we in the Government really intend to assure contract compliance with safety as we do with quality, production, and delivery schedules.

However, it is realized that complying with everyone of the mandatory safety requirements in the DoD Manual is in some cases difficult.

The Military Services realize this too, as prior to DCAS they were in the field doing the same job that we are doing today.

To go on, the DoD Manual specifically established a criteria dealing with noncompliance with mandatory safety requirements, and this is how it works.

Paragraph 104, Noncompliance with Mandatory Safety Requirements of the DoD Manual, establishes the procedures to be followed.

During the preaward phase, the contracting officer may accept the existing conditions in a Defense contractor's facilities. This acceptance prior to award of the contract eliminates the requirement for waivers or exemptions.

However, prior to the acceptance of these existing conditions, all areas of noncompliance with the mandatory safety requirements must be clearly established. Experience over the past few years has confirmed that contracting officers are not prone to accept "carte blanche" a contractor production facility without a reasonable effort by industry to reduce the risk to an acceptable level.

In some cases such as the requirement for "fire symbols", a suitable alternate is usually acceptable.

The significant item that I want to establish is that noncompliance with mandatory safety requirements can, in most cases, be easily resolved at the time of the preaward survey if contractor representatives examine the intent of these standards and clearly state what corrective action will be accomplished in the event of award.

This will allow the contracting officer and his safety representative to objectively evaluate the recommendations and findings of the preaward survey.

If the preaward is not complete concerning these safety items, problems usually develop during the post award conference and on future post award safety surveys.

Remember, if during a post award conference or survey your production plans or facility layout is significantly changed from that submitted to the Government during the preaward survey, these changes must be submitted to the contracting officer for evaluation. These discrepancies will be considered for waivers or exemptions and when necessary for a contract adjustment in accordance with ASPR 1-109.

In view of the seriousness of noncompliance with mandatory safety requirements, it is of the utmost importance that you actively participate in the preparation of bids to insure that you can comply with either the requirement or intent of the safety standards. Because if you don't you are putting your employer at a disadvantage which could result in either non-award or contract adjustments.

Questions:

PRESENTATION FOR THE ASESB SEMINAR ON SAFETY AND ENVIRONMENTAL CONSIDERATIONS IN AMMUNITION DISPOSAL

by

John D. Connelly
Office of The Chief of Naval Operations - OP41D

THE OFFICE OF THE CHIEF OF NAVAL OPERATIONS IN COLLABORATION WITH THE OCEANOGRAPHER OF THE NAVY, THE COMMANDER NAVAL ORDNANCE SYSTEMS COMMAND, AND THE COMMANDING GENERAL ARMY MATERIAL COMMAND IS VERY PLEASED TO BRING YOU THIS PRESENTATION ON THE SAFETY AND ENVIRONMENTAL ASPECTS OF AMMUNITION DISPOSAL METHODS. WE BRING YOU THIS BASICALLY AS A MEANS OF LAYING BEFORE YOU, YOUR COLLECTIVE ABILITIES, AND MINDS, WHAT WE CONSIDER TO BE A PROBLEM OF MAJOR PROPORTIONS AND ONE WHICH DAILY INCREASES IN GRAVITY. TO SUM UP THE PROBLEM LET ME SHOW YOU NOW WHAT I MIGHT CALL THE "MILITARY DILEMMA". (SLIDE 1) WE'RE CONCERNED TODAY WITH "HOW DO WE THROW IT AWAY "SAFELY, AND CLEANLY?"

AS YOU KNOW, BASICALLY, AMMUNITION IS BUILT TO STAY TOGETHER, IT IS BUILT STURDILY BECAUSE OF THE VERY CONSIDERABLE ACCELERATION, DECELERATION, AND IMPACT FORCES THAT IT HAS TO WITHSTAND, NOT TO MENTION THE RIGORS OF HANDLING, TRANSPORTATION, ENVIRONMENTAL CHANGES, ETC. (SLIDE-2 - TYPICAL AMMO ITEMS)

I AM GOING TO GIVE YOU VERY BRIEFLY AN OVERVIEW OF THE DISPOSAL PICTURE AND THEN MY COLLEAGUES WILL GO INTO MORE DETAIL.

WHEN OBSOLESCENCE OR DETERIORATION OR ANY OTHER REASON CAUSES A REQUIREMENT FOR AMMUNITION DISPOSAL IT MAY BE IN TERMS OF JUST A FEW ROUNDS BUT GENERALLY THOUSANDS OF ROUNDS AND POSSIBLY THOUSANDS OF TONS ARE INVOLVED. NOW THERE ARE A NUMBER OF WAYS THAT THE MATERIAL CAN BE DISPOSED OF. IF IT IS SMALL ENOUGH IT CAN BE "POPPED" IN A FURNACE: (SLIDE 3) UP TO 20MM SIZE CAN BE PULLED APART TO SEPARATE THE CARTRIDGE CASE FROM THE PROJECTILE, AND THEN THE POWDER BURNED, AND THE PROJECTILE AND CARTRIDGE CASE "POPPED." (SLIDE 4) LARGER ROUNDS CAN BE TAKEN APART, THAT IS, DEMILITARIZED, BY FUZE REMOVAL; WASHING, STEAMING, OR DRILLING OUT THE HIGH EXPLOSIVE CHARGE AND THEN DISPOSAL OF THE EXPLOSIVE IN SOME WAY SUCH AS BURNING OR DETONATION. BOMBS, SEA MINES, AND AMMUNITION OF THAT NATURE CAN GENERALLY BE DEMILLED IN THE SAME WAY. NOT ALL AMMUNITION CAN BE DEMILLED - THERE IS ALWAYS SOME WHICH MUST BE DETONATED.

THESE TYPES OF OPERATIONS PARTICULARLY WHEN PURSUED ON A MASS-PRODUCTION BASIS MAY PRODUCE AIR POLLUTION, NOISE POLLUTION, WATER POLLUTION, COMBINATIONS OF EACH AND, ON OCCASION, A GREAT DEAL OF PUBLIC RESENTMENT. THE PARAMOUNT CONSIDERATION, OF COURSE, IS SAFETY: THE SAFETY OF THOSE DOING THE OPERATIONS, AND THE PROTECTION OF THE GOVERNMENT EQUIPMENT AND PROPERTY INVOLVED IN THE DEMILITARIZATION AND DISPOSAL EFFORTS. MOST DEMILITARIZATION AS PRACTICED TODAY HAS SOME INHERENT DEGREE OF DANGER, SOMEWHERE IN THE OPERATION. WE CAN AND DO SURROUND THE OPERATION WITH AS MANY SAFEGUARDS AS POSSIBLE. FOR EXAMPLE, WE CAN AUTOMATE AND ISOLATE THE EQUIPMENT AND OPERATE IT REMOTELY. WE CAN DO A LOT OF THINGS. BUT WE CAN'T FULLY GUARANTEE SAFETY. I'D LIKE TO SHOW YOU NOW JUST TWO OF OUR LITTLE HORROR STORIES: THESE TWO SLIDES (SLIDE 5) SHOW THE EFFECTS OF A RECENT EXPLOSION AT NAD HAWTHORNE, NEVADA, BY A 3.5 INCH SHAPED CHARGE ROCKET HEAD WHICH WAS BEING PREPARED FOR DISPOSAL. 3 DEATHS RESULTED. (SLIDE 6) THE NEXT SLIDE IS OF AN INCIDENT WHICH OCCURRED EARLIER THIS YEAR: (SLIDE 7) YOU SEE WHAT WAS LEFT OF A 20MM DEMILITARIZATION LINE. HERE THE OPERATION WAS SUDDENLY STEPPED UP FROM ONE PROJECTILE AT A TIME, TO 20,000 . THEY WENT HIGH ORDER, IN A MASS DETONATION. 2 DEATHS.

ANOTHER FORM OF DISPOSAL WHICH THE SERVICES HAVE USED FOR MANY YEARS IS DEEP WATER DUMPING, (SLIDE 8) IN WHICH THE MATERIAL IS SIMPLY CARRIED OUT TO A SELECTED DUMP SITE AT LEAST TEN MILES FROM ANY SHORE AND AT LEAST 500 FATHOMS DEEP AND THEN IS DROPPED TO THE OCEAN FLOOR OR, AS HAS BEEN THE PRACTICE IN THE PAST EIGHT OR NINE YEARS IN OUR SO-CALLED "CHASE" OPERATIONS, THOUSANDS OF TONS OF DISPOSAL MATERIAL HAVE BEEN PLACED IN MERCHANT SHIP HULLS AND TAKEN OUT TO SEA AND SCUTTLED.
TWO OF MY COLLEAGUES ARE GOING TO DESCRIBE FOR YOU IN SOME DETAIL THE DISPOSAL METHODS IN WHICH THE ORDNANCE IS PHYSICALLY ATTACKED IN SOME MANNER. SO THAT YOU WILL HAVE A FULL OVERVIEW OF THE DISPOSAL PROBLEM, I WILL BRIEFLY ACQUAINT YOU WITH THE DEEP WATER DUMP METHOD. TO ACCOMPLISH THIS A MERCHANT HULK IS TAKEN FROM THE MARITIME ADMINISTRATION RESERVE AND CONDITIONED FOR THE OPERATION, THAT IS, ANYTHING WHICH IS READILY REMOVABLE OR LOOSE ONBOARD SHIP IS REMOVED, AND THE FUEL TANKS OF THE SHIP ARE CLEANED TO ELIMINATE ANY OIL CONTAMINATION. SCUTTLING VALVES ARE INSTALLED TO ALLOW THE WATER TO ENTER THE SHIP, AND SOFT PATCHES ARE INSTALLED IN THE BULKHEADS BETWEEN HOLDS TO ALLOW THE WATER TO SPREAD EVENLY THROUGH THE SHIPS.

THE HULK IS THEN POSITIONED AT ONE OF TWO NAVAL DEPOTS, EITHER AT EARLE, NEW JERSEY OR THE FORMER NAVAL AMMUNITION DEPOT AT BANGOR, WASHINGTON. THE MATERIAL FOR DUMPING IS THEN MADE NEGATIVELY BUOYANT SO IT WON'T FLOAT TO THE SURFACE, AND LOADED INTO THE HULK. THIS MATERIAL, I MIGHT ADD, HAS IN THE PAST GENERALLY INCLUDED QUANTITIES OF AIR FORCE AND ARMY AMMUNITION TOO.

(SLIDE 9) THIS IS A DIAGRAM OF A SHIP RIGGED FOR DWD. WHEN THE HULK IS LOADED AND THE OPERATION HAS BEEN CLEARED WITH ALL RESPONSIBLE AUTHORITIES IT IS THEN TOWED UNDER NAVAL ESCORT TO THE DUMPING AREA AND SCUTTLED. NOW IN SOME CASES, AT THE REQUEST OF THE SCIENTIFIC COMMUNITY, WE HAVE DELIBERATELY DETONATED THESE HULKS ON THEIR WAY TO THE BOTTOM.

IN SEVERAL OTHER CASES THE HULKS HAVE DETONATED OF THEIR OWN ACCORD, FOR WHAT PARTICULAR REASON WE DON'T KNOW. WE CAN SPECULATE A LOT OF THINGS, A LOT OF PRESSURES, AND SHIFTING, AND CRUSHINGS THAT WOULD GO ON AT DEPTH. SO, AT ANY RATE, THEY HAVE DETONATED OF THEIR OWN ACCORD. NOW A FEW REPRESENTATIVE PICTURES TO GIVE YOU A FEEL FOR THE PROCESS: (DWD SLIDES) (1-LOADING; 2-SHIP UNDER TOW; 3-SHIP SINKING; 4-SHIP ALMOST UNDER; 5-ALL GONE.) WE ARE PRESENTLY NOT DOING ANY DWD WHATSOEVER. EARLIER THIS YEAR THE SECRETARY OF THE NAVY DECIDED THAT WE - THE NAVY - DID NOT REALLY KNOW ENOUGH ABOUT THE ENVIRONMENTAL IMPACT OF OCEAN DISPOSAL OF AMMUNITION AND ABOUT THE ALTERNATE DISPOSAL METHODS AVAILABLE. NOW, THE NAVY HAS ALWAYS BEEN IN THE FOREFRONT, AMONG THE LEADERS IN FIGHTING POLLUTION. WE KNOW THERE's A GREAT DEAL OF WORK TO BE DONE IN POLLUTION ABATEMENT AND AVOIDANCE AND WE CAN POINT TO MANY POSITIVE ACTIONS IN THESE AREAS.

RIGHT HERE IN SAN DIEGO, FOR EXAMPLE, THE NAVY HAS ELIMINATED OPEN BURNING OF TRASH, CONVERTED ALL SHORE BASED POWER PLANTS TO GAS OR LOW-SULFUR FOSSIL FUELS, IS SPENDING OVER A MILLION DOLLARS TO CONTROL POLLUTANTS FROM THE FIREFIGHTING SCHOOL, HAS TAKEN MANY, MANY STEPS TO CONTROL ITS POLLUTION POTENTIAL AND ASSIST THE COMMUNITY IN SUCH PROGRAMS AS REMOVING LITTER FROM THE BEACHES AND BAYS. IN THE FACE OF THE TREMENDOUS EFFORT BEING MADE AND THE DOLLARS BEING SPENT NAVY-WIDE IN POLLUTION CONTROL AND ABATEMENT, IT WAS INCONSISTENT TO CONTINUE PUTTING OUR AMMO IN THE OCEANS WITHOUT ANY POSITIVE KNOWLEDGE OF WHETHER OR NOT WE WERE CREATING POLLUTION OR ALTERING THE ENVIRONMENT. THE SECRETARY THEREFORE SUGGESTED TO THE SECRETARY OF DEFENSE THAT DWD BE SUSPENDED UNTIL THIS TYPE OF INFORMATION COULD BE DEVELOPED, AND MR. LAIRD CONCURRED IN THIS MORATORIUM.

THE NAVY HAS FORMED A COMMITTEE TO STUDY, IN DEPTH, ALTERNATIVE METHODS OF DISPOSAL. THE CHIEF OF NAVAL OPERATIONS HAS ESTABLISHED A TWO-FOLD PROGRAM: FIRST, TO DEVELOP SAFER, MORE ENVIRONMENTALLY ACCEPTABLE METHODS OF AMMUNITION DISPOSAL; AND

SECOND, TO ANALYZE AND ASSESS THE IMPACT OF PAST DEEP WATER DUMPS ON THE ECOSYSTEMS OF THE OCEAN. IN THE NEXT TWO PRESENTATIONS YOU WILL HEAR THE RESULTS OF THE NAVY'S WORK TO DATE, IN THESE AREAS. FIRST, TO COMPLETE THE PICTURE ON DEEP WATER DUMPING, CAPTAIN BILL REED, REPRESENTING THE OCEANOGRAPHER OF THE NAVY, WILL TALK TO YOU ON THE OCEANOGRAPHIC WORK WHICH HAS BEEN DONE ON PAST DEEP WATER DUMP SITES TO FIND OUT WHAT HARM, IF ANY, HAS BEEN DONE TO THE OCEANS BY THIS METHOD OF DISPOSAL. THEN MR. BOB ROACH OF THE NAVAL ORDNANCE SYSTEMS COMMAND, WILL DESCRIBE HOW AMMUNITION IS BEING DISPOSED OF TODAY BY THE NAVY, AND WHAT NEW DEVELOPMENTS ARE UNDER STUDY. MR. FRANK CRIST WILL THEN DESCRIBE THE ARMY'S VERY PROGRESSIVE DEVELOPMENT PROGRAM FOR AMMO DISPOSAL, AND THEN WE WILL MAKE OURSELVES AVAILABLE FOR QUESTIONS.

ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF PAST DEEP WATER DUMPING OPERATIONS

by

Captain William F. Reed, Jr., USN

Office of the Oceanographer of the Navy

I. Introduction

A. Remarks and History

Mr. Connelly has outlined the background of numbered DWD operations. Of the nineteen numbered MARAD hulks scuttled in that program, fifteen cargos were composed of explosive ordnance only and four carried chemicals. Three of the explosive ordnance laden hulks settled to the sea floor without detonation. The remaining twelve detonated during scuttling.

B. Moratorium

In the fall of 1970 the Council on Environmental Quality recommended termination of the disposal of munitions by dumping at sea and on 7 October 1970, President Nixon stated that he would recommend legislation to stop the use of the sea as a dumping ground. Immediately the Secretary of the Navy placed a moratorium on DWD operations. It was becoming apparent that the ocean was finally gaining the stature that some think it deserves.

C. Program Authorization

Because of the importance of the ocean environment, the Chief of Naval operations in April 1971 directed the Oceanographer of the Navy to institute a program to:

1. Prepare a comprehensive environmental condition report for representative past explosive ordnance DWD sites.

2. Develop criteria for selection of future sites in the event that DWD is resumed.

3. Determine what monitoring efforts would be required at DWD sites in the future.

I should emphasize that this program extends to conventional explosives only. The much publicized nerve gas disposal is being handled by a separate monitoring program.

II. Magnitude of the Problem

To design the program we had to consider the questions that would have to be answered. The general public often views ordnance related operations with an eye to catastrophic possibilities and ocean dumping in general as undefined, but probably bad. There has been alarm over possible mass fish kills and the creation of major dead areas on the sea floor. It has been feared that dumping would degrade the ability of the environment to support life or to support the normal marine food chain. This meant that evidence of toxicity from heavy metals or explosive components would require investigation, and the possible return of any contaminants to the surface waters would require detailed assessment. Habitat changes resulting from the physical presence of debris on the ocean floor or from explosions cratering the bottom are also items of question, as is any evidence of possible long term hazard to the marine biota or to future ocean exploitation. In short, the overall physical environment at dump sites would have to be carefully sampled and sample results compared to the dynamics of the living populations. Since not all fifteen deep explosive disposal sites could be investigated, representative sites have been selected. These are: an area off Cape Flattery in the Pacific where five ships were sunk and exploded in 8,400 feet of water and an area 175 miles southeast of Charleston where one ship was sunk and did not explode, in 6,300 feet of water. Any successful measurement program would require precise location of the scuttled hulks or their debris -- a major task in 6,000 to 8,000 feet of water.

The requirement for results by early calendar 1972, and the need to utilize available technical resources already committed to existing projects, were additional factors. In essence we had an operational project which would contribute to scientific knowledge and which had to be constructed as a scientific experiment. I think it worthwhile to note that the fulfillment of this unique operational task is dependent upon research efforts only recently completed or still in progress. This is one more example of the importance of a vigorous continuing research and development program.

III. Approach

Our first step was to review in depth all past DWD related efforts and literature as to oceanographic characteristics of the environment at the DWD sites. This preliminary study will be a part of our final report. As part of this data search we reviewed DWD cargo composition, individual site characteristics and navigational information in order to choose sites which were representative of all DWD operations and which we had a reasonable probability of locating. As I said, we wound up choosing a site in the Pacific and one in the Atlantic

The first is comprised of five exploded hulks and the other a single unexploded one. The cargo composition scuttled at these sites is typical of past DWD operations and of munitions that still await disposal. The depths are similar to those that would be used if there were any future such operations. While we were choosing our sites we were also assembling our team to whom I must give credit. In the Pacific the Marine Physical Laboratory of Scripps Institution of Oceanography handled the search and location phase using their sonar and camera equipped "Fish", which is an unmanned vehicle which carries cameras, side-scan sonar, a magnetometer and a transponder, so that its location can be accurately fixed. It is towed across the bottom on the end of a coaxial cable. This search phase was completed on 25 July 1971.

The environmental survey is underway now off Cape Flattery and includes collection of water and bottom samples, benthic biological specimens, and the measurement of horizontal and vertical currents. Oregon State University is handling the biological portion of the work with the remainder accomplished by the Naval Oceanographic Office. In the Atlantic, search and location operations, and all of the survey except the biological portion, will be accomplished by the Naval Research Laboratory on the USNS MIZAR with assistance from the Naval Oceanographic Office. Biological work will be the responsibility of Florida State University. In addition to the biological work being accomplished by the consultants, subsamples of water, sediment and fauna will be distributed to various Navy laboratories for analysis as to the presence of heavy metals and munitions products. These analytical assignments have been made on the basis of each lab's specific area of competence. In addition to samples at the debris sites we will of course take control samples remote from the site but at the same depth. Our specifications for the survey have been checked and commented upon by members of the Ocean Affairs Board of the National Academy of Sciences. When the study is complete we will have a highly informed opinion, verified by scientific procedures, as to the changes in the overall marine life and environment between the control station and the actual sites themselves.

This slide, which is our sampling plan at Cape Flattery, gives an idea of the detail to which we will work. The circle in the center of the cross hatched area is the radius of debris that we have already determined. At each of the triangular marks which indicate major stations we will take the complete gamut of physical, chemical, bottom and biological samples that I have already mentioned. At these two marks indicated by squares we will emplant current arrays and also take radon diffusion measurements so that we can determine the horizontal and vertical currents at the time of the survey. These black dots indicate the eight STD casts we will make from which we will get an idea of the general regime surrounding the area. As you can see, the overall survey area is approximately 60 miles square.

IV. Results to Date

I am pleased to report that our progress in the search and survey program has been highly satisfactory to date. Dr. Spiess, Mr. Saunders and their team from Scripps located all five of the hulks that had been sunk off Cape Flattery and all were within a radius of five miles. This slide illustrates the search track of the "Fish". While the directions may appear haphazard, they were dictated by the weather, the location of transponders on the bottom, and the problem of stabilizing the "Fish" at the start of each run. The track shows the survey density and illustrates that we can be pretty sure there was no wreckage in the area that we did not locate. Five distinct debris patches were found as shown on this chart of the bottom. In each case the debris was in an elliptical shaped pattern approximately 1,400 feet long and 900 feet wide. Apparently, after the explosion the debris rained straight down onto the ocean bottom. Each of the areas had a definite boundary, and the wreckage was fairly well concentrated in a large mound in the areas indicated. Photographs and side-scan sonar indicate that there were very few large pieces -- the largest projection from the bottom was apparently 30 feet.

The majority of the wreckage consisted of finely shredded metal. This is a picture of one of the side-scan sonar traces which is typical of all. It illustrates a football shaped area of approximately uniform density with relatively few large projections. Here is a typical shot of the wreckage. Apparently it is resting on or partially embedded in sediment. There is no evidence of any cratering of the ocean floor that we can locate. Of course one of the big questions is the effect upon the life down here, if any: have the naturally occurring marine organisms returned to the area and what is their approximate density and distribution. Here are some examples. Unfortunately, I cannot say this young lady is typical. She is just what oceanographers would like to find. These pictures taken as the fish transsected the wreckage from side to side are perhaps more illustrative of the actual conditions. This slide of the ocean floor near the wreckage shows sea cucumbers or Holothurians and worm holes. As we get into the edge of the wreckage area you can see crabs, sea urchins and so forth along the bottom. A substantial number of organisms typical to the general region are apparently residing within the debris area.

That, gentlemen, completes our progress to date and our plans. We will finish the survey in the Pacific on the 16th of September, and do our field work in the Atlantic from the 15th of November to the 15th of December. After analyzing the data we collect, we will submit a complete environmental report to the Chief of Naval Operations approximately the end of January 1972.

AMMUNITION EXPLOSIVES & OTHER DANGEROUS ARTICLES, DEMILITARIZATION & DISPOSAL PROGRAM

by

Mr. J. R. Roach
Naval Ammuniton Production Engineering Center

AS MENTIONED EARLIER, THERE HAS BEEN A NATIONAL POLICY ESTABLISHED BANNING DEEP WATER DUMP AS A METHOD OF DEMILITARIZATION/DISPOSAL. UNTIL THIS BAN, THE NAVY DEPENDED UPON DEEP WATER DUMP AS THE MAIN METHOD FOR DISPOSING OF OBSOLETE OR UNSERVICEABLE ORDNANCE. OVER 100,000 TONS OF ORDNANCE HAS BEEN DEEP WATER DUMPED SINCE 1964 IN THE SPECIALLY PREPARED LIBERTY SHIPS AS SHOWN IN THE SLIDE. THE USE OF THIS METHOD PRECLUDED ANY REQUIREMENTS FOR MAINTAINING LARGE ENGINEERING GROUPS AND ELABORATE EQUIPMENT AND FACILITIES SPECIFICALLY FOR DEMILITARIZATION/DISPOSAL OPERATIONS. THE NAVY DID, IN FACT, PUT ITS DEMIL PROBLEMS IN THE DRINK. BECAUSE OF THIS CHANGE IN NATIONAL POLICY AND ADDITIONAL IMPENDING FEDERAL AND STATE REGULATIONS CONCERNING POLLUTION ABATEMENT AND CONTROL OF ALL TYPES, THE SECRETARY OF THE NAVY ESTABLISHED A HIGH LEVEL TECHNICAL WORKING GROUP TO EVALUATE PRESENT PRACTICES AND TO CONSIDER FUTURE POSSIBILITIES FOR DEMIL OF AMMUNITION. AS YOU CAN IMAGINE, SINCE THE CESSATION OF DEEP WATER DUMP, THE TASK OF ROUTINE DEMIL/DISPOSAL HAS BECOME AN ENORMOUS CHALLENGE TO BOTH THE TECHNICAL AND FINANCIAL RESOURCES OF THE NAVY. WHEREAS, PREVIOUSLY, WE COULD GET RID OF MUNITIONS IN QUANTITIES AS LARGE AS 8,700 TONS AT A TIME WITH DEEP WATER DUMP, WE ARE NOW FORCED INTO EXPLOSIVE ORDNANCE DISPOSAL (E.O.D.) AND OTHER METHODS ON A PRODUCTION BASIS. FOR LARGE ORDNANCE ITEMS SUCH AS MAJOR CALIBER PROJECTILES, THIS ENTAILS WORKING WITH SMALL QUANTITIES OF THE ORDNANCE USING MANUAL UNDERGROUND EMPLACEMENT AND DETONATION. EXPLOSIVE ORDNANCE DISPOSAL TECHNIQUES AND OPERATIONS HAVE BEEN REQUIRED SINCE THE DAYS OF THE AMERICAN CIVIL WAR. THE STORY IS TOLD OF A RECENT INCIDENT IN WHICH EXPLOSIVE ORDNANCE DISPOSAL PERSONNEL WERE CALLED TO THE COUNTRY HOME OF A

1 Slide of Liberty Ship

2 Slide of 16" Proj.

NORTH CAROLINA WOMAN WHERE UPON ARRIVAL, THEY OBSERVED CLOTHES (PANTS, SHIRTS,
DRESSES, SHEETS, ETC.) SCATTERED UPON THE GROUND AND IN THE TREES BEHIND THE
CALLER'S HOUSE. ON INVESTIGATION, IT WAS DISCOVERED THAT THE WOMAN WHO LIVED
THERE HAD NO WASHING MACHINE AND HAD FOR YEARS BOILED HER CLOTHES IN A WASHTUB
(3) SUPPORTED ON THREE LARGE CIVIL WAR ARTILLERY SHELLS. ON ITS LAST WASHDAY, SHE
Slide of Civil War Artill. Shell — SET THE TUB ON TOP OF THE SHELLS AND BUILT A FIRE UNDER IT AS SHW HAD FOR
YEARS. INSIDE THE HOUSE A FEW MINUTES LATER, SHE HEARD WHAT SHE DESCRIBED AS
A CLAP OF THUNDER. RETURNING TO CHECK HER WASH, SHE FOUND A HOLE WHERE THE
Off — WASHTUB HAD BEEN AND HER BACKYARD ARRAYED WITH CLOTHES. THOUGH THIS PROCEDURE
(4) CERTAINLY DEMILED AN OBSOLETE ORDNANCE ITEM, IT IS NOT CONSIDERED TO BE SAFE
Slide of Misc. Civil War Ordnance — AND ECONOMIC IN TERMS OF WASHTUBS AND CLOTHES. THIS TYPE OF OCCURRENCE WILL
ALWAYS BE WITH US ON A "ONESEY - TWOSEY" BASIS AS OBSOLETE ORDNANCE IS
DISCOVERED THROUGHOUT THE WORLD. THIS TYPE OF DISPOSAL, HOWEVER, IS NOT OUR
Off — PROBLEM. OUR PROBLEM IS A BACKLOG CURRENTLY ESTIMATED AT SOME 80,000 TONS OF
AMMUNITION FOR DEMIL/DISPOSAL WITH MORE EXPECTED TO BE GENERATED AS THE SOUTH-
EAST ASIA SITUATION WINDS DOWN.

(5) HERE IS A BREAKDOWN OF THE TOP TEN ORDNANCE ITEMS IN OUR BACKLOG FOR DEMIL/
Slide of Top Ten — DISPOSAL. THESE ITEMS REPRESENT THE NAVY'S TEN LARGEST QUANTITIES OF SPECIFIC
TYPES OF ORDNANCE FOR DISPOSAL. YOU WILL NOTE THAT WE HAVE 72 MILLION ROUNDS
Off — OF 20MM AMMUNITION AND 21 MILLION ROUNDS OF .50 CAL. AMMUNITION FOR DEMIL/
(6) DISPOSAL. (PAUSE) YOU WOULD NOT THINK THAT DEMILING 20MM AND .50 CAL.
Slide of McA Bldg. Destroyed — AMMUNITION WOULD PRESENT MUCH OF A PROBLEM BUT HERE IS THE TRAGIC RESULT OF
AN ACCIDENT INVOLVING THE DEMILITARIZATION OF 20MM AMMUNITION. A BREAKDOWN OF
Off — OUR ENTIRE 80,000 TON BACKLOG OF MUNITIONS REQUIRING DEMIL/DISPOSAL SHOWS
(7) THESE QUANTITIES BY TYPES. ABOUT 50,000 TONS CAN BE DEMILITARIZED. ALMOST
Slide of Inventory — ALL OF THE RECLAIMED ACTIVE INGREDIENTS (EXPLOSIVES AND OTHER ENERGETIC

Off

MATERIALS) CAN BE RECYCLED FOR REUSE OR RESALE. IT IS EXPECTED THAT APPROXIMATELY 7,000 TONS OF HBX; 6,000 TONS OF TNT; AND 15,000 TONS OF SMOKELESS POWDER CAN BE RECLAIMED. IN ADDITION, THERE ARE APPROXIMATELY

(8) Slide of Current Operations

5,000 TONS OF EXPLOSIVE SCRAP FOR WHICH RECYCLING MAY BE POSSIBLE. OUR CURRENT OPERATIONS INCLUDE THE FOLLOWING DEMIL PROCEDURES. THEY HAVE BEEN UNDERWAY SINCE THE FIRST QUARTER OF CALENDAR YEAR 1971. (PAUSE)

OFF

(9) Slide of Cal. Rd.

.50 CAL. .50 CAL AMMUNITION IS RUN THROUGH A RETORT FURNACE WHERE DETONATION OCCURS AND THE ROUNDS ARE DEMILITARIZED, RESULTING IN SALVAGABLE METALS.

(10) Slide of Furn. Ld.

MK-51 MINES THESE UNDERWATER MINES CONTAIN APPROXIMATELY 3,200 POUNDS OF

(11) Slide of Furn Dis

TNT. THE TNT IS STEAMED OUT OF THE MINES AND COLLECTED USING A DRUM FLAKER. THE FLAKED TNT IS REPROCESSED AND LOADED INTO OTHER ORDNANCE OR STORED FOR

(12) Slide of Mine on Truck

FUTURE USE. ANY REMAINING TNT IN THE MINE CASE IS BURNED AND THE EMPTY MINE CASE IS CUT UP FOR SALE AS SCRAP METAL. USING THIS METHOD, APPROXIMATELY

(13) Slide of Mine Steam Out

4,200,000 POUNDS OF TNT HAS BEEN RECLAIMED FOR POSSIBLE REUSE.

(14) Slide of Drum Flaker

SCRAP AND WASTE EXPLOSIVE IS BEING BURNED IN OPEN GROUND BURNING AREAS. INCINERATION OF SMALL ARMS AMMUNITION AND MISCELLANEOUS ORDNANCE IS BEING CARRIED ON IN BURNING PITS DESIGNED FOR SMALL QUANTITIES. THE ORDNANCE IS

(15) Slide of Empty Mine Cases

DROPPED THROUGH A TUBE INTO A CONTAINED FIRE.

(16) Slide of Burn Grd.

EXPLOSIVE ORDNANCE DISPOSAL PERSONNEL ARE DETONATING LARGE MUNITIONS IN REMOTE DEMOLITION GROUNDS. IN FACT, A SPECIFIC EXPLOSIVE ORDNANCE DISPOSAL UNIT HAS

(17) Slide of Burn Pit

DISPOSED OF OVER 2,500 TONS OF UNSERVICEABLE ORDNANCE SINCE THE FIRST QUARTER OF FISCAL YEAR 1971. TO REACH THIS TOTAL REQUIRED 40 TO 60 DETONATIONS EVERY

OFF

(18) Slide of Demolition Grounds

WEEK DAY, WHEN THE WEATHER PERMITTED. ACTUALLY, WEATHER PERMITTING, THE

DETACHMENT CAN EFFECTIVELY DISPOSE OF 40 TONS OF ORDNANCE PER DAY. THOSE ITEMS DESTROYED INCLUDE 500 POUND MINOL LOADED BOMBS, 16" PROJECTILES, 5" PROJECTILES, ASSORTED BOMB BOOSTERS AND BURSTERS, SEVERAL VARIETIES OF FUZES, PHOTOFLASH BOMBS AND CARTRIDGES, 7.2" HEDGEHOGS, AND OTHER VARIOUS ITEMS. THESE ITEMS VARY IN PERCENTAGE OF EXPLOSIVE LOAD FROM APPROXIMATELY 8 PERCENT TO 80 PERCENT. UP TO 40 PITS ARE FILLED WITH ORDNANCE AND THEN PRIMED AND TAMPED WITH ABOUT 10 TO 16 FEET OF DIRT. THE FUZE SYSTEM CONSISTS OF EXPLOSIVE SQUIBS AND PRIMER CORD ASSEMBLIES GOING TO THE ORDNANCE IN EACH PIT WHERE THE DETONATIONS

19 Slide of 16" Proj & Rockeye

TAKE PLACE AT INTERVALS OF 5 SECONDS. THIS SLIDE IS AN EXAMPLE OF HOW A COMBINATION OF UNSERVICEABLE OR OBSOLETE ROCKEYE BOMBLETS AND 16" PROJECTILES IS ARRANGED FOR DISPOSAL BY THIS METHOD.

OFF

20 Slide of Earle Facility

A NOVEL PROTOTYPE BULK MUNITIONS INCINERATOR IS BEING ERECTED AT A NAVAL ACTIVITY BY A COMMERCIAL FIRM FOR THE DEMIL OF SOME 500 GROSS TONS OF MISCELLANEOUS FUZES IN SUCH A MANNER THAT WILL MEET WITH SAFETY REQUIREMENTS AND COMPLY WITH EXISTING FEDERAL AND STATE POLLUTION REGULATIONS. (PAUSE)

OFF

THE WAYS OF DEMIL THAT I HAVE JUST DESCRIBED ARE EXAMPLES OF OUR CURRENT METHODS; HOWEVER, WE ARE LOOKING FORWARD TO BETTER METHODS AND PROCEDURES FOR DEMIL, INCLUDING THOSE IN THE REPORT OF THE SPECIAL TECHNICAL WORKING GROUP THAT WAS PREVIOUSLY MENTIONED.

21 Slide of Future OP.

THE DEVELOPMENT OF A FLEET OF MOBILE DEMIL PLANTS WHICH MAY BE DEPLOYED AND SET UP IN THE FIELD IN A MANNER SIMILAR TO ASPHALT PLANTS IS ONE ALTERNATIVE.

OFF

22 Slide of Mobile Furn.

AS AN EXAMPLE, THIS SLIDE IS AN ARTIST'S CONCEPTION OF A MOBILE DEMIL FURNACE FACILITY CAPABLE OF DEMILING 20MM AND SMALLER AMMUNUTION. THE AMMUNITION WOULD BE FED INTO THE SYSTEM AT THIS POINT, BROKEN DOWN AS REQUIRED SO THAT THE PROPELLANT WOULD BE RECLAIMED AND THE CARTRIDGE PRIMER FIRED RESULTING

IN SALVAGABLE BRASS. THE PROJECTILE WOULD BE CONVEYED THROUGH THE FURNACE RETORT FOR DETONATION OR BURNING AND THIS METAL COULD ALSO BE SALVAGED. ALL NECESSARY SUPPORT EQUIPMENT, SUCH AS UTILITIES, MOBILE REPAIR SHOPS, POLLUTION CONTROL EQUIPMENT, ETC., COULD BE MADE AVAILABLE AS REQUIRED. THE MOBILE DEMIL SYSTEM COULD BE SENT OUT AND ERECTED AT NAVY FIELD ACTIVITIES. THE SYSTEM WOULD BE OPERATED BY FIELD ACTIVITY PERSONNEL USING STANDARD OPERATING PROCEDURES. THE EXPECTED ADVANTAGES OF SUCH A SYSTEM WOULD BE MINIMUM TRANSPORTATION OF UNSERVICEABLE ORDNANCE, FLEXIBILITY OF DEMIL SITES THROUGH THE USE OF MODULAR MOBILE SYSTEMS, LOW CAPITAL INVESTMENT AND RAPID RESPONSE TO

OFF

PRIORITY DEMIL/DISPOSAL REQUIREMENTS. OTHER MOBILE SYSTEMS COULD BE DEVELOPED TO WASHOUT AND STEAMOUT ENERGETIC MATERIALS FROM ORDNANCE, REPROCESS AND

23
Slide of Commer. Incinerator

RECLAIM THEM AND INCINERATE THEM IN CLOSED COMMERCIALLY AVAILABLE INCINERATORS WITH SELF CONTAINED POLLUTION CONTROL EQUIPMENT AS SHOWN IN THE SLIDE FROM A BROCHURE OF A COMMERCIAL VENDOR OF SUCH EQUIPMENT. ANOTHER ALTERNATIVE BEING CONSIDERED IS AN ULTRA MODERN PERMANENT ORDNANCE DEMIL/RENOVATION FACILITY

OFF

LOCATED AT ONE OR TWO ACTIVITIES IN THE UNITED STATES. THIS ALTERNATIVE COULD PROVIDE FACILITIES FOR BOTH ORDNANCE RENOVATION AND FOR ALL DEMIL/DISPOSAL AT ONE LOCATION. A SYSTEMATIC ANALYSIS OF THESE ALTERNATIVES FOR DEMIL FACILITIES FOR THE NAVY HAS BEEN INITIATED. THE INTENT OF THE NAVY'S DEMIL PROGRAM IS TO DISPOSE OF ORDNANCE IN THE SAFEST MOST EFFECTIVE MANNER. THE TWO FACILITY ALTERNATIVES THAT HAVE JUST BEEN DISCUSSED WOULD INVOLVE

24
Slide of Max. Recycling & Salvage

PROCESSES FOR MAXIMUM RECYCLING AND SALVAGE OR RESULTING PRODUCTS AND BY-PRODUCTS FROM DEMILITARIZATION OPERATIONS.

THE THEME OF MAXIMUM RECYCLING OF UNSERVICEABLE OR OBSOLETE ORDNANCE IS OF GREAT INTEREST, FOR THE VALUES OF RECYCLING ARE OBVIOUS. IN ADDITION TO RECYCLING EXPLOSIVES FOR REUSE IN MILITARY HARDWARE, THE CONVERSION OF

RECLAIMED EXPLOSIVES FOR USEFUL DOMESTIC PURPOSES AND PRODUCTS SUCH AS FERTILIZERS AND SANITARY LAND FILL IS ALSO BEING CONSIDERED. EXTRA EFFORT WILL BE EXTENDED TO MAKE MILITARY EXPLOSIVES AVAILABLE FOR COMMERCIAL APPLICATIONS

OFF

SUCH AS FOR COMPOUNDS USED IN EXPLOSIVE SLURRIES USED BY THE TACONITE MINING INDUSTRY. AT THE SAME TIME, IN ORDER TO BETTER UTILIZE RECLAIMED EXPLOSIVES, BETTER TECHNIQUES FOR EXPLOSIVE REMOVAL ARE BEING DEVELOPED. WHERE IT IS NOT

25

Slide of Alternatives

FEASIBLE TO DEMIL ORDNANCE IN A MANNER TO OBTAIN RECYCLING OR SALVAGE, THESE ALTERNATIVES APPEAR TO OFFER PROMISE.

CONTAINED DETONATION AND INCINERATION INVOLVE THE USE OF LARGE SPECIAL RETORTS AND MODIFIED COMMERCIALLY AVAILABLE WASTE INCINERATORS. THOUGHT IS ALSO BEING GIVEN TO USING LARGE REINFORCED CONCRETE WALLED, WATER FILLED VESSELS FOR CONTAINMENT OF DETONATIONS. THIS APPROACH COULD ELIMINATE MANY OF THE DRAWBACKS OF PRESENTLY USED OPEN PIT AND GROUND BURNING AND DETONATING PROCEDURES.

REMOTE DETONATION COULD OFFER PROMISE BY USING:

1. HOLES AND VOIDS CAUSED BY UNDERGROUND NUCLEAR BLASTS AS A RESULT OF THE ATOMIC ENERGY COMMISSION WORK, OR
2. COMBINING ORDNANCE WITH THE NUCLEAR EXPLODING DEVICE IN FUTURE UNDERGROUND ATOMIC TESTS
3. ABANDONED MINES

MUCH WORK IS YET NECESSARY, HOWEVER, IN EVALUATING THESE ALTERNATIVES.

EQUALLY IMPORTANT TO WHAT WE ARE DOING TO SOLVE THE PROBLEM WE HAVE IS WHAT THE NAVY IS DOING TO REDUCE OR ELIMINATE THE PROBLEM IN THE FUTURE. THIS

OFF COMES UNDER THE HEADING OF DESIGNING FOR DISPOSAL. WE SHOULD TAKE SOME LESSONS FROM THE EARLIER INHABITANTS OF OUR COUNTRY. THEY DESIGNED ORDNANCE WHICH COULD READILY BE DEMILITARIZED AND DISPOSED OF IN A SAFE AND NON-POLLUTING MANNER. (PAUSE) BUT SINCE WE TEND TO COMPLICATE MATTERS, METHODS OF DEMIL/DISPOSAL WILL HAVE TO BE DEFINED IN THE DEVELOPMENT OF NEW WEAPONS AND WEAPONS SYSTEMS.

26
Slide of Indian Ord Items

OFF

27
Slide of Design for Disp.

WEAPONS WILL BE DESIGNED FOR SAFE DISARMING, DEFUZING, DEMILING AND DISPOSAL. FUTURE DEVELOPMENT OF EXPLOSIVES WILL TAKE INTO CONSIDERATION THEIR FUTURE DISPOSAL WHEN THEIR MILITARY USE IS NO LONGER REQUIRED.

PLANNED PROJECTS REPRESENTING SUCH AN IDEA ARE:

USE OF BINARY EXPLOSIVES WHICH IS PERHAPS THE MOST APPEALING OF ALL PROPOSALS TO ELIMINATE THE PROBLEM RATHER THAN TO SOLVE IT. A BINARY EXPLOSIVE, FOR EXAMPLE, WOULD CONSIST OF RELATIVELY INERT COMPONENTS UNTIL MIXED. IDEALLY SUCH MATERIALS WOULD ONLY BE MIXED WHEN THE ORDNANCE WAS COMMITTED TO THE TARGET OR AS SHORTLY AS POSSIBLE BEFORE IMPACT WITH THE TARGET. THUS AT NO OTHER TIME, WOULD A TRUE EXPLOSIVE EXIST. SUCH MUNITIONS COULD BE DISPOSED OF FAR MORE SAFELY AND ECONOMICALLY THAN OUR PRESENT MUNITIONS CAN.

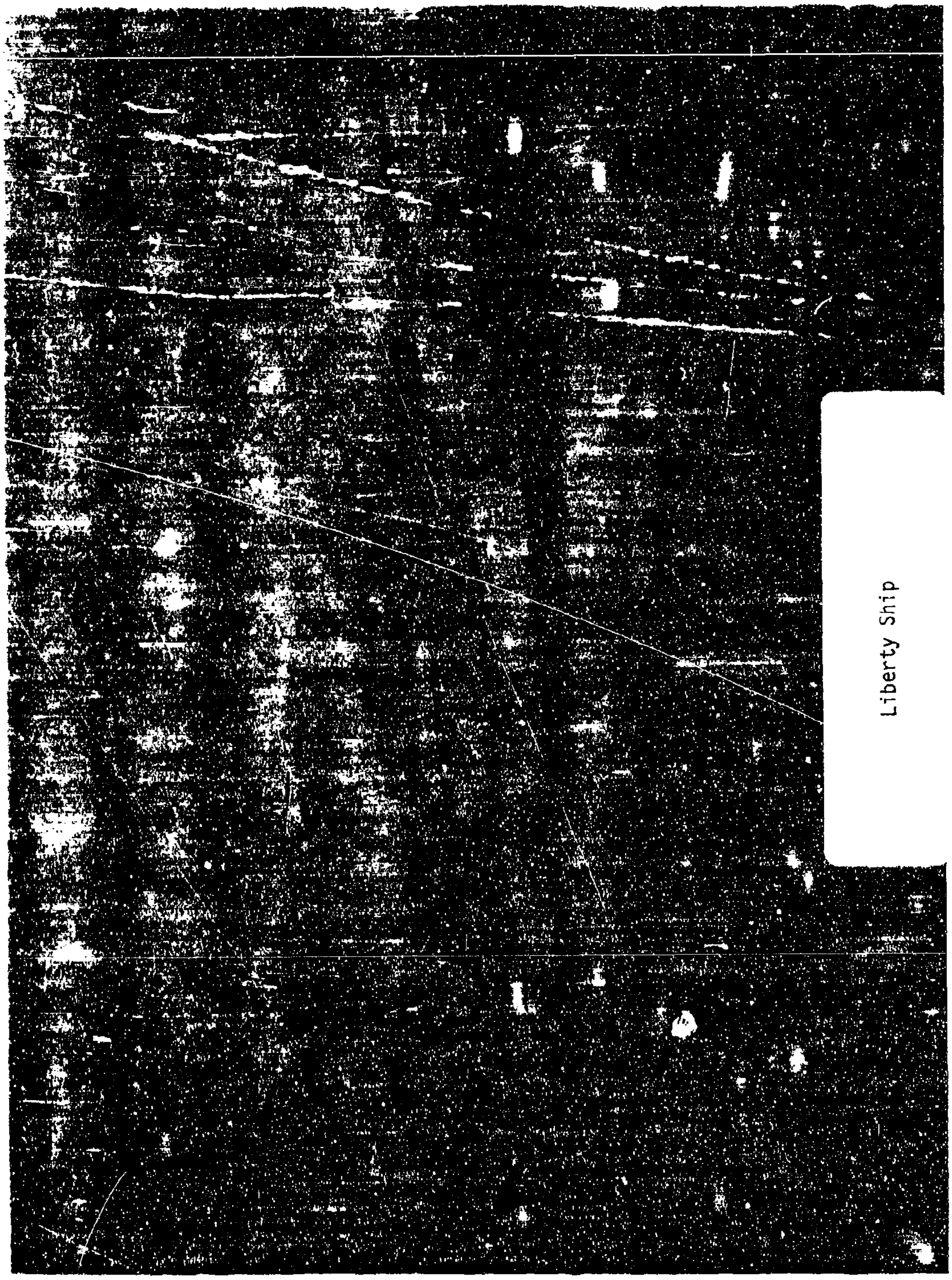
A POSSIBILITY ALSO EXISTS THAT SOME EXPLOSIVES MAY BE BIODEGRADABLE. AN INVESTIGATION IS PRESENTLY UNDER WAY TO IDENTIFY THE EXPLOSIVES AND THE ORGANISMS. SHOULD THIS PROVE FEASIBLE FOR MOST EXPLOSIVES, IT COULD HAVE A PROFOUND EFFECT UPON FUTURE DESIGN OF WEAPONS FOR DISPOSABILITY. IN ADDITION, EXPLOSIVES OR TOXIC MATERIALS MUST READILY BE REMOVABLE FROM ORDNANCE. POSSIBLE TECHNIQUES INCLUDE EXPLOSIVE REMOVAL BY DISSOLVING IN WATER AND

DISSOLVING IN ACIDS. OF COURSE, COMPONENTS ON A NEWLY DEVELOPED WEAPONS AND WEAPON SYSTEM MUST BE READILY CONVERTED FOR REUSE OR NON-POLLUTING DISPOSAL.

I HAVE DISCUSSED THE NAVY'S AMMUNITION DISPOSAL SITUATION FROM THE WAY WE USED TO DO IT, OUR CURRENT OPERATIONS AND OUR PLANS FOR THE FUTURE. WE HAVE MADE AND PLAN TO CONTINUE VISITS TO OTHER SERVICES AND COMMERCIAL FACILITIES WHERE NEW METHODS ARE BEING DEVELOPED FOR ORDNANCE DEMIL. WE ARE FOLLOWING THEIR WORK IN THIS AND RELATED FIELDS VERY CLOSELY AND CERTAINLY WELCOME THEIR HELP AND SUGGESTIONS.

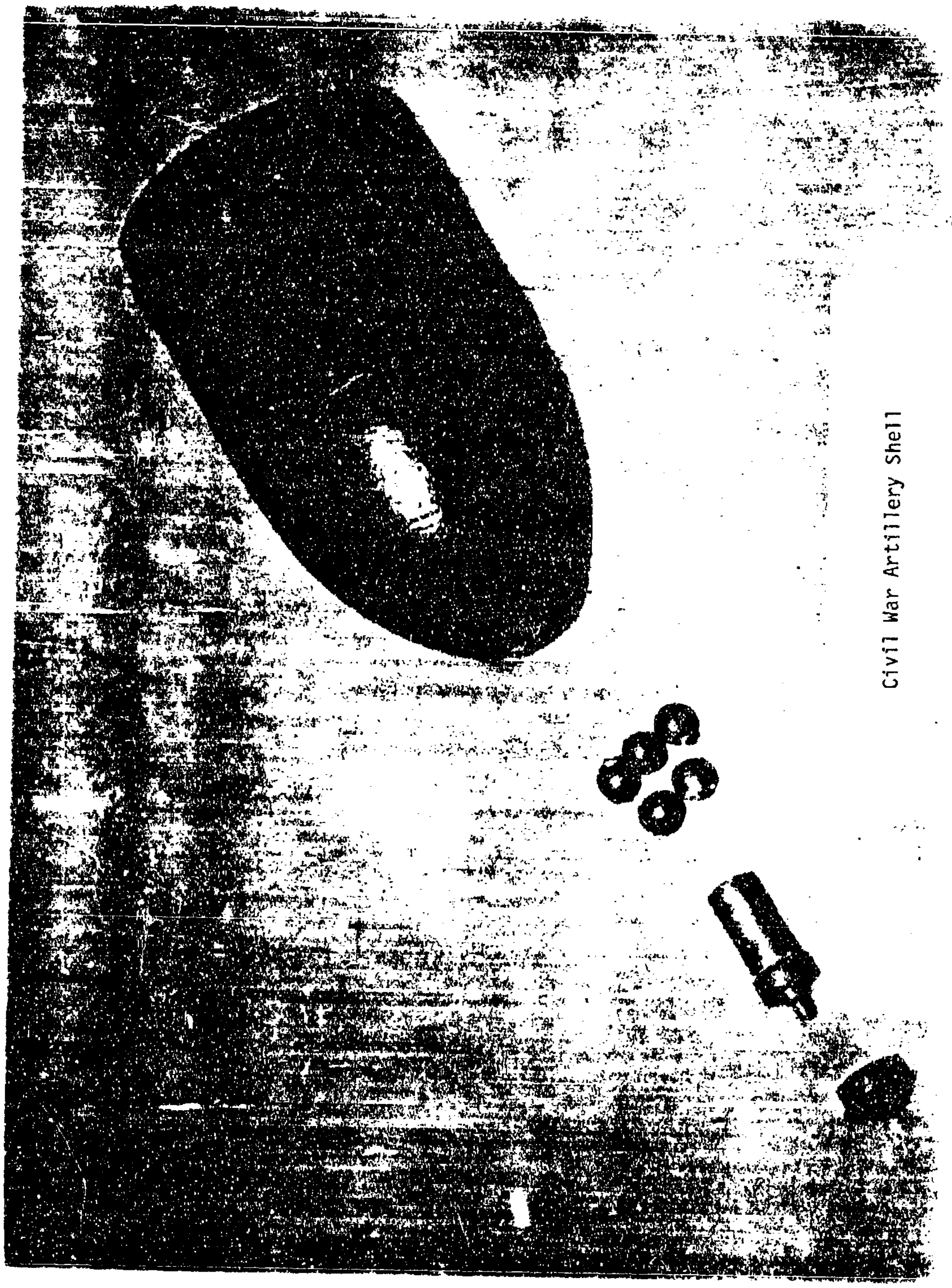
AS YOU CAN SEE, WE DO HAVE CHALLENGES WHICH WE RECOGNIZE. WE ARE PROCEEDING AS RAPIDLY AS POSSIBLE TO FIND ACCEPTABLE WAYS OF MEETING THEM. WE ARE DETERMINED TO MEET THESE CHALLENGES OF ORDNANCE DEMIL/DISPOSAL WITH DUE REGARD FOR THE ENVIRONMENT OF NOT ONLY THE INDIVIDUAL WORKER BUT ALSO THE ENTIRE COMMUNITY.

PRESENTATION GIVEN TO THE ARMED SERVICES EXPLOSIVES SAFETY BOARD 13TH ANNUAL SEMINAR AT SAN DIEGO, CALIFORNIA, ON 15 SEP 1971 BY J. R. ROACH - STAFF SUPERVISOR AEDA DEMILITARIZATION/DISPOSAL STAFF, NAVAL AMMUNITION PRODUCTION ENGINEERING CENTER, CRANE, INDIANA.

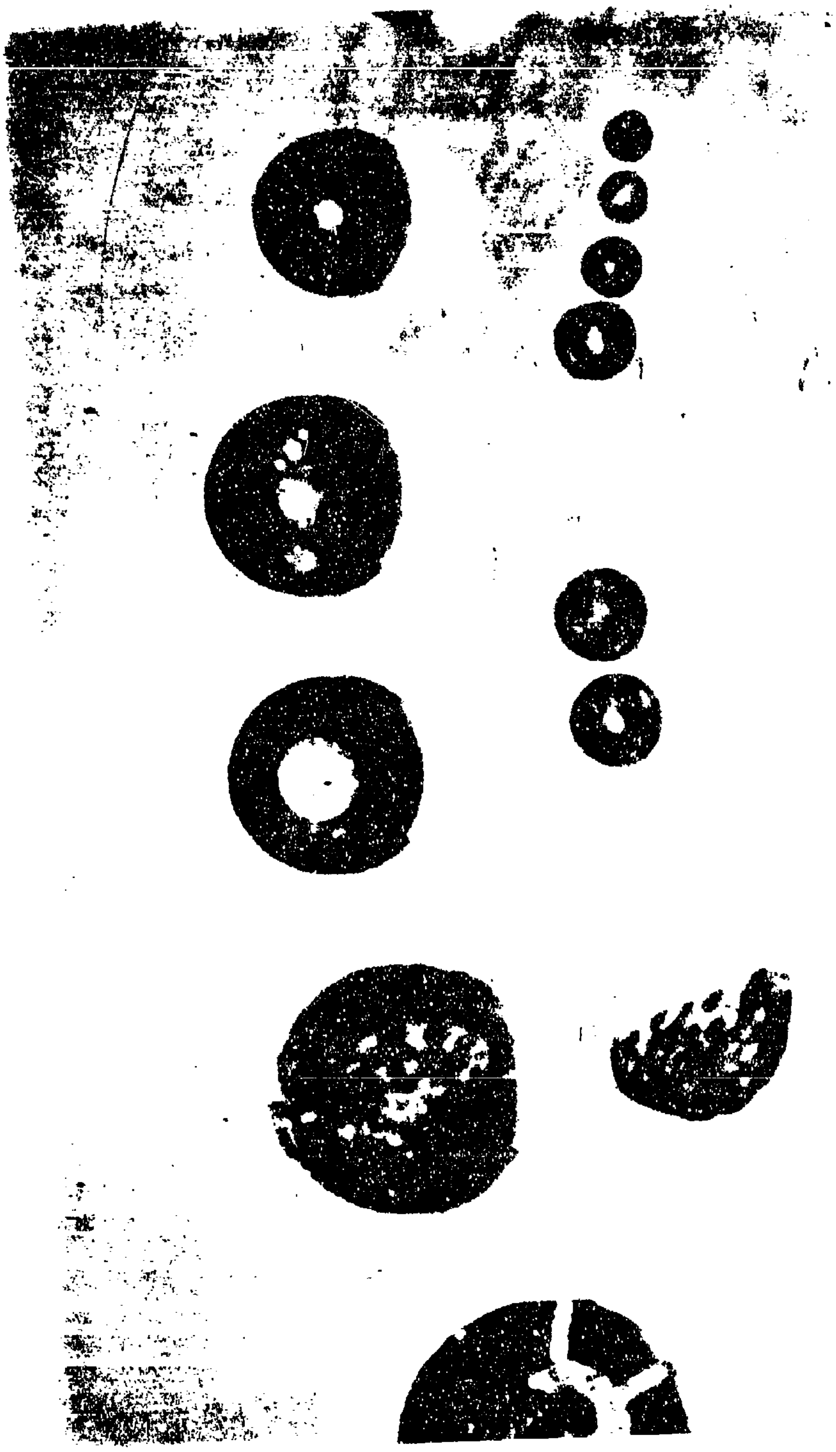


Liberty Ship

16" Projectile



Civil War Artillery Shell



Miscellaneous Civil War Ordnance

TEN LARGEST QUANTITIES OF ORDNANCE AVAILABLE FOR DISPOSAL

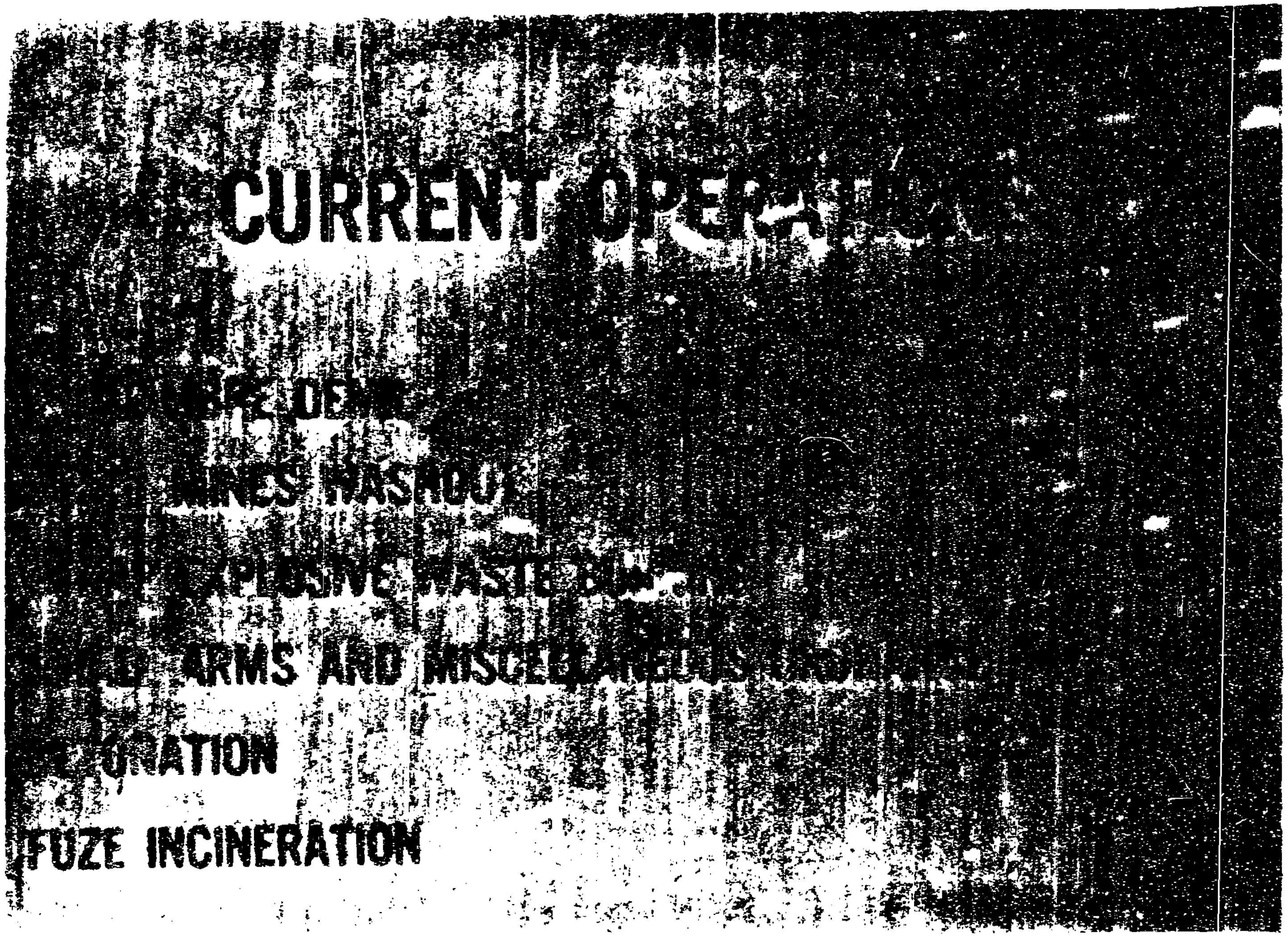
[illegible]	QUANTITY (EACH)
CARTRIDGE, 20MM	72,202,800
CASE, MINE, HBX LOADED	17,000
ROCKET, 2.25 INCH	115,900
CHARGE, PROPELLANT 155MM	219,800
CASE, MINE TNT LOADED	4,800
CASE, DEPTH CHARGE, TNT LOADED	19,900
CARTRIDGE, 50 CAL.	21,093,200
FUZE, POINT DETONATING, MK 78	86,500
CARTRIDGE, 3"/50	130,200
CHARGE, 120MM	15,500

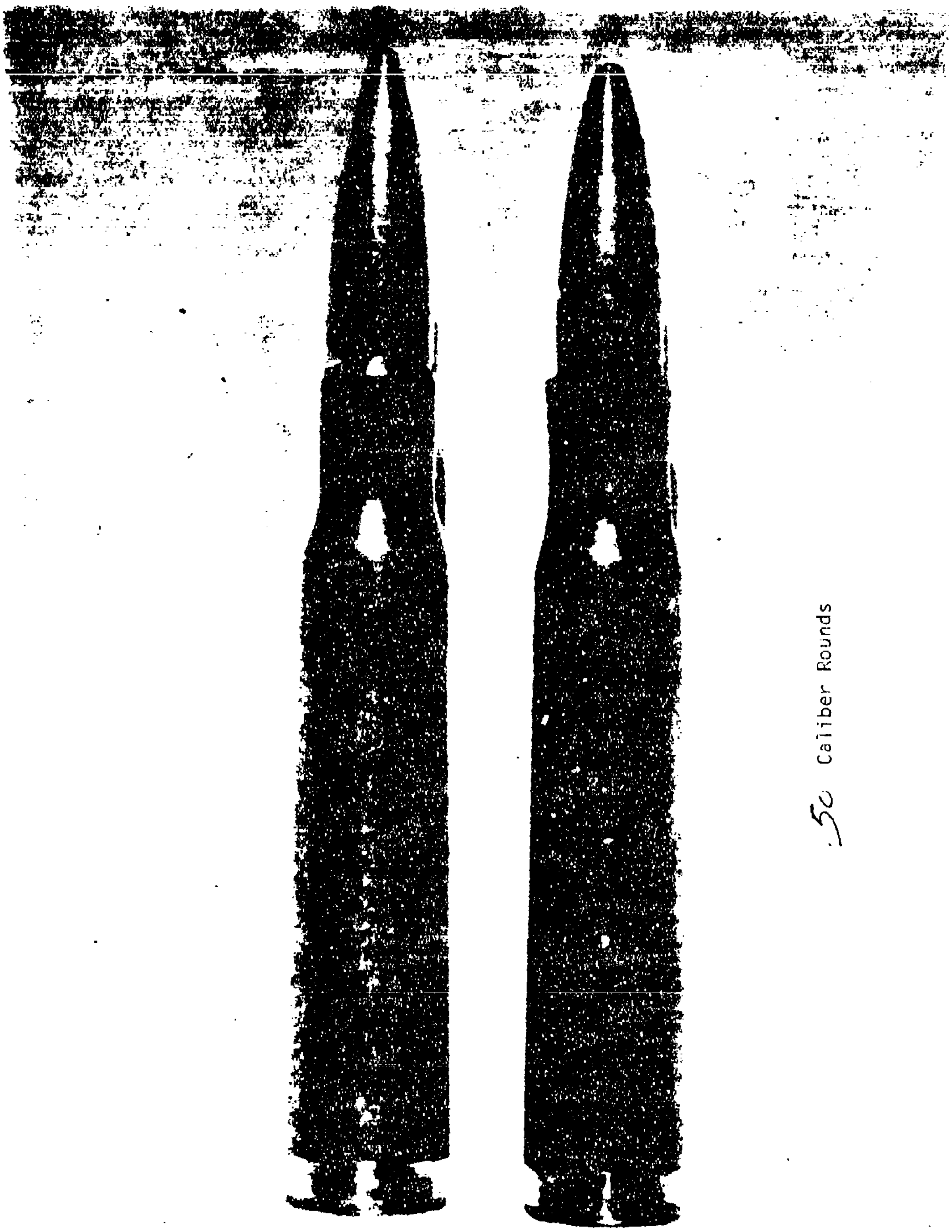
McAlester Building Destroyed

COMPREHENSIVE INVENTORY FOR DISPOSAL

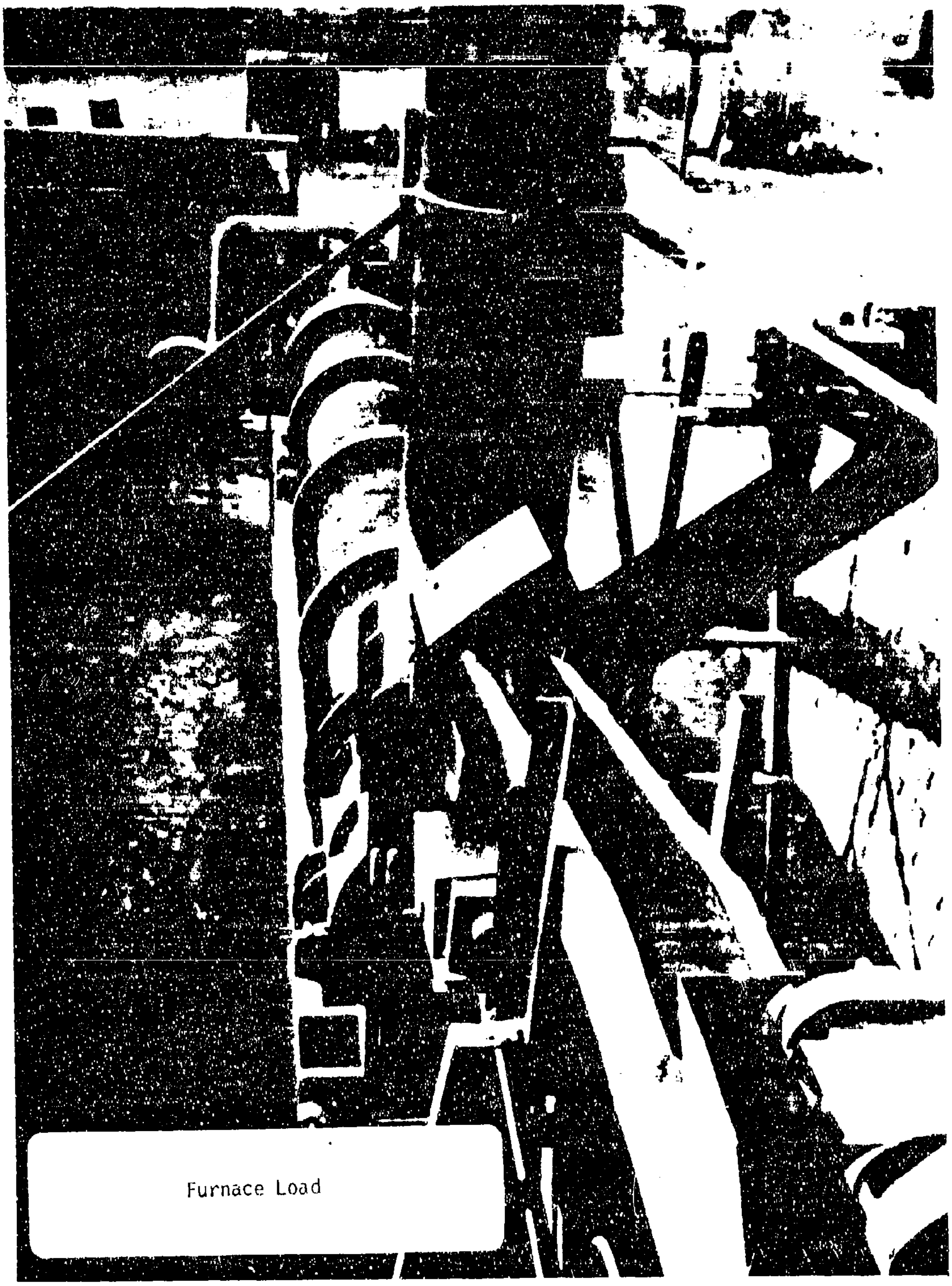
AMMUNITION AND EXPLOSIVES SCHEDULED AS OF MARCH 1971 FOR DISPOSAL ARE [illegible]

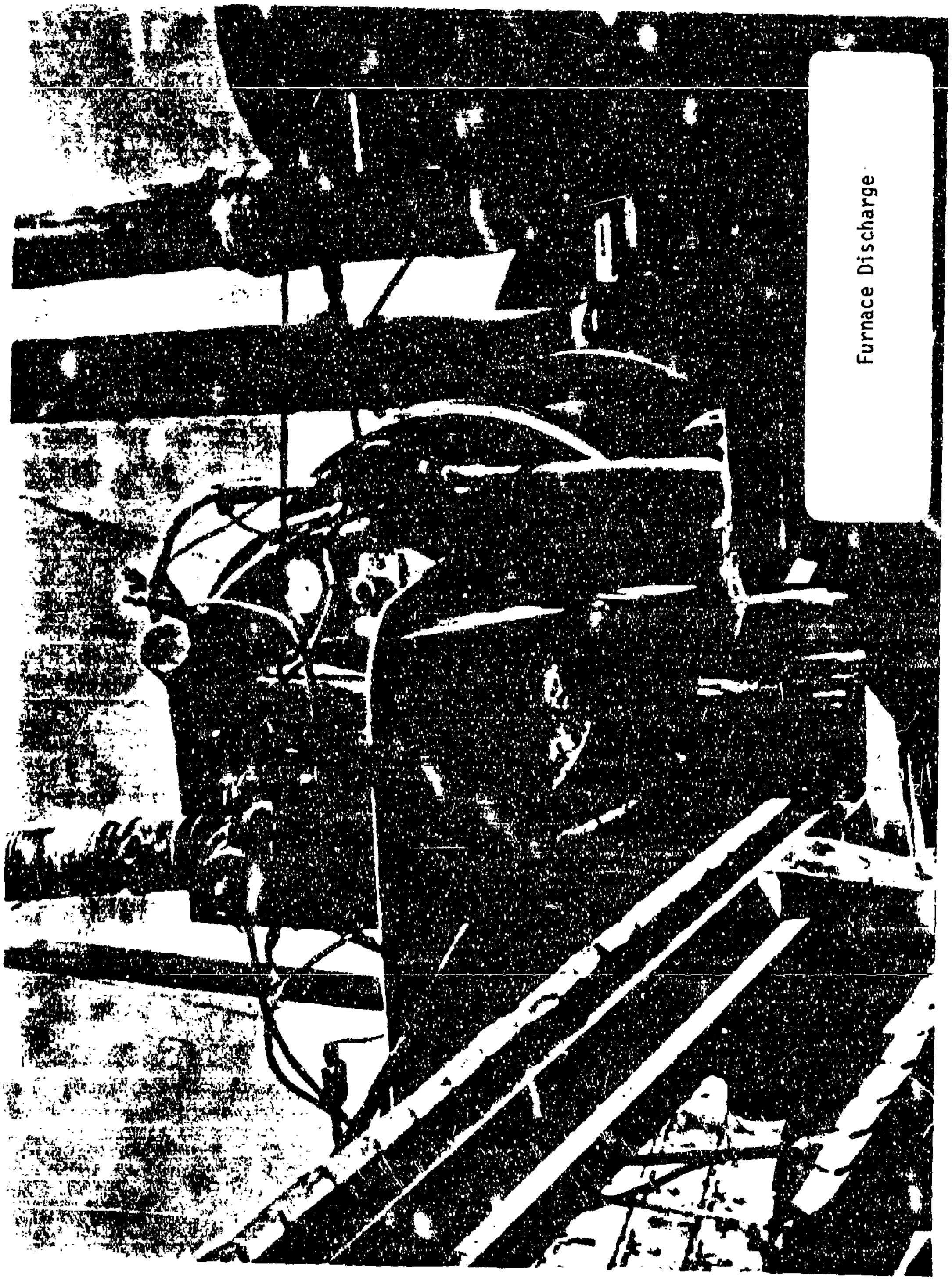
TYPE	QUANTITY [illegible]
BOMBS	2,300
DEPTH CHARGES/UNDERWATER SIGNALS	5,700
UNDERWATER MINES/TORPEDOES	16,200
ROCKETS/GUIDED MISSILES	7,600
SMALL ARMS	3,400
GUN AMMUNITION (20MM TO 4")	29,200
GUN AMMUNITION (4" TO 16")	5,900
PYROTECHNIC SIGNALS, DEMOLITION CHARGES, FUZES, CADs, AND MISCELLANEOUS ITEMS	600
BULK PROPELLANT ROCKET GRAINS	6,600
TOTAL	77,500


CURRENT
EXPLOSIVE WASTE
ARMS AND
FUZE INCINERATION

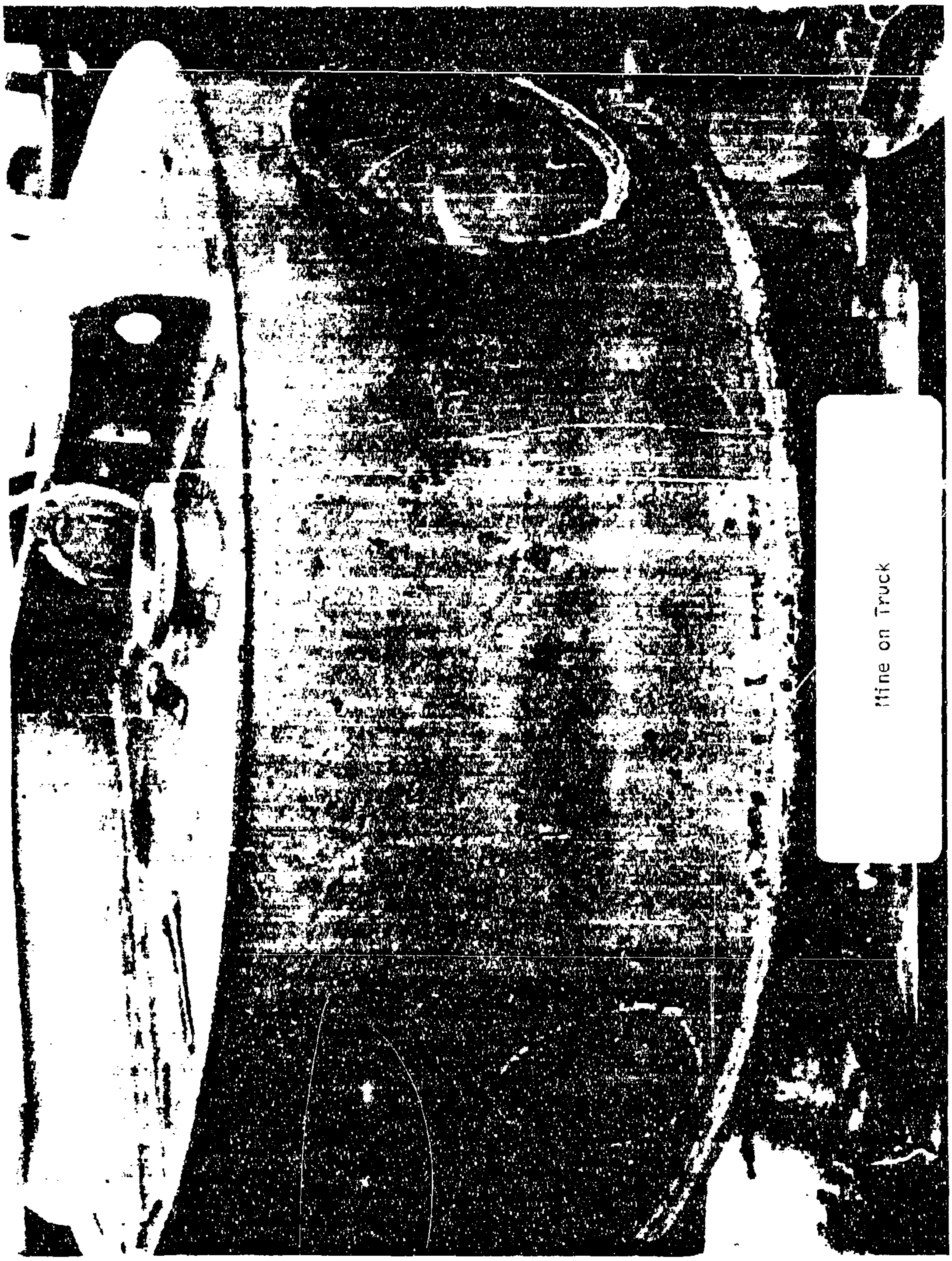


.50 Caliber Rounds


Furnace Load

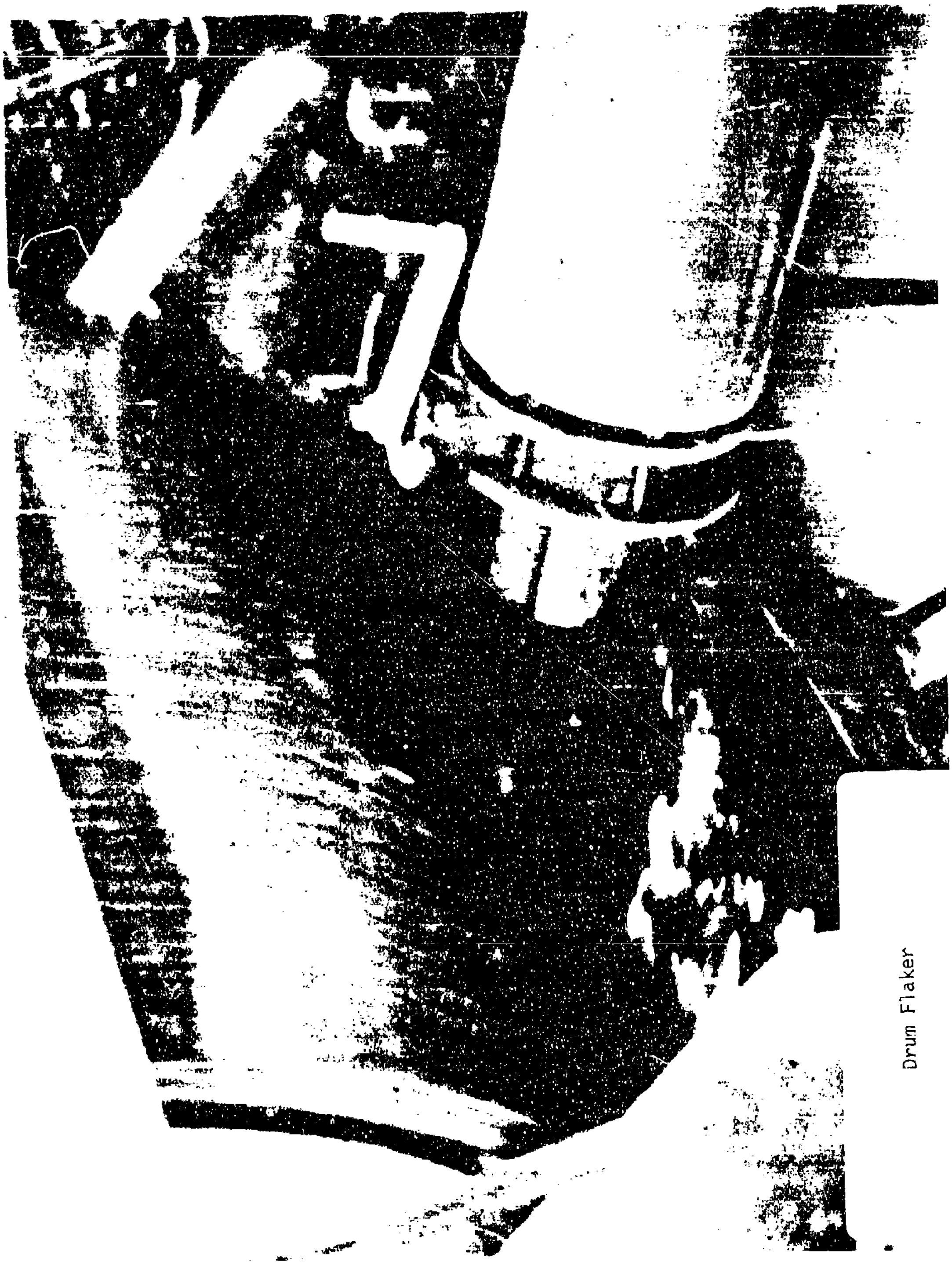


Furnace Discharge



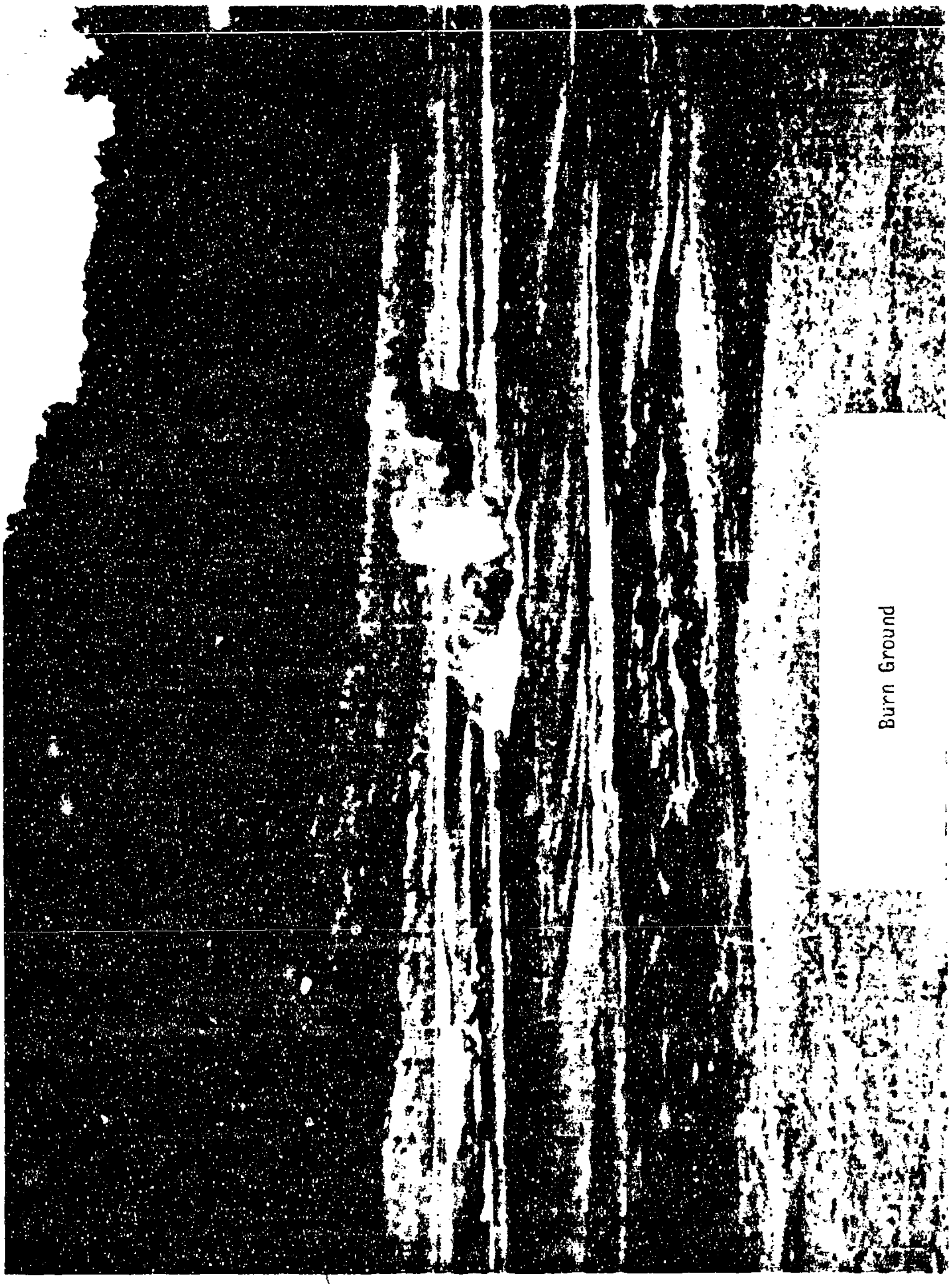
Mine on Truck

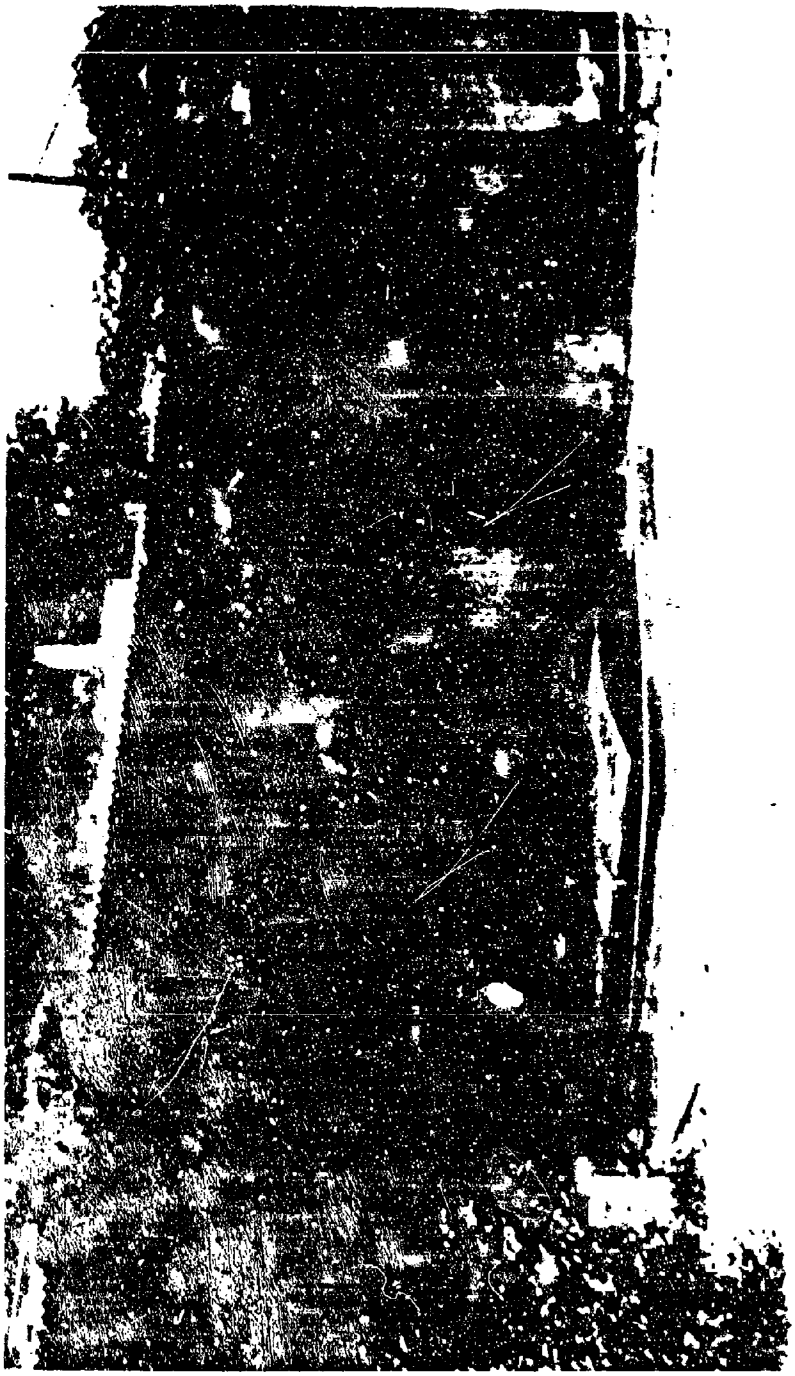
Mine Steam out



Drum Flaker

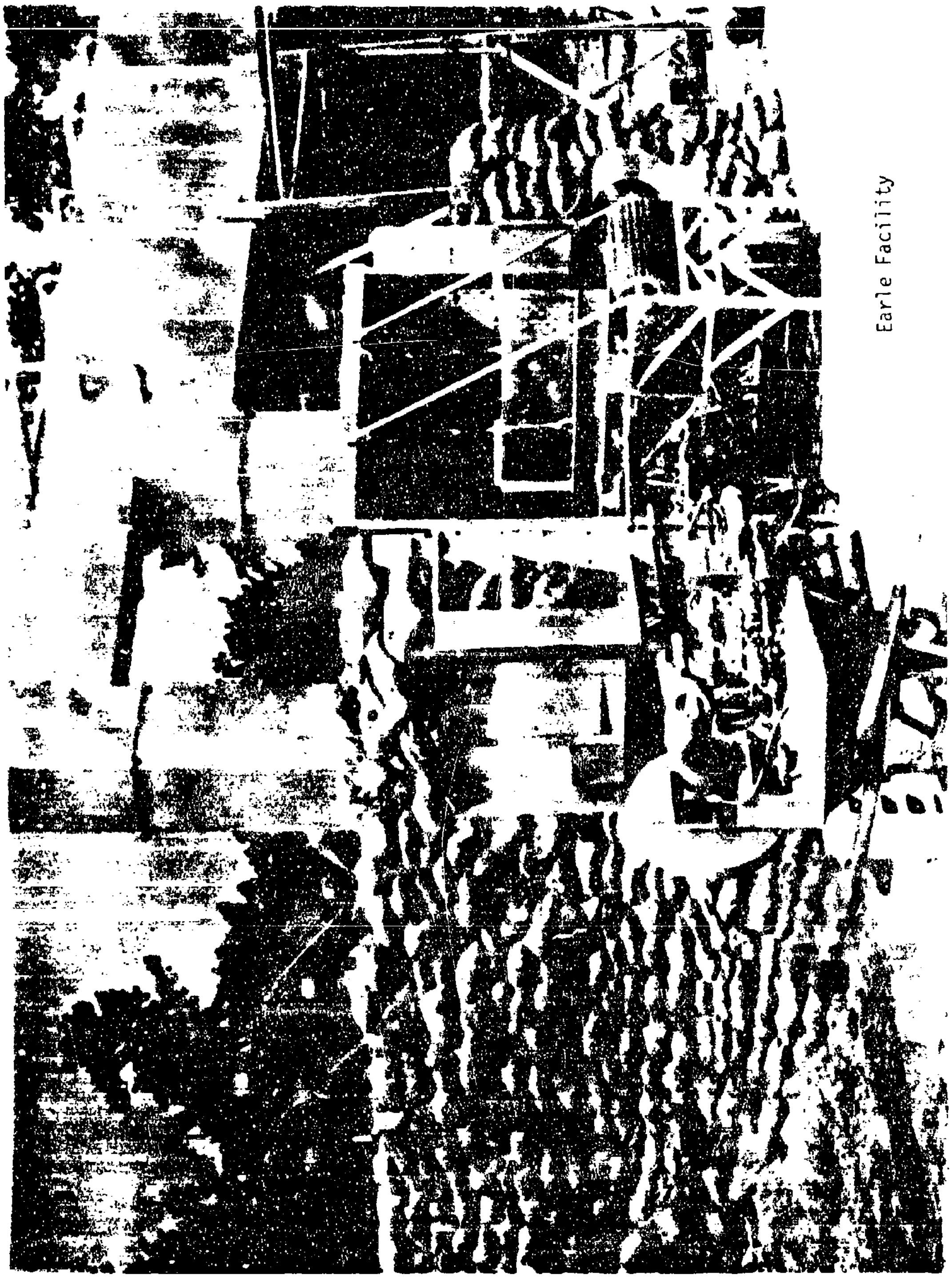
Empty Mine Cases


Burn Ground



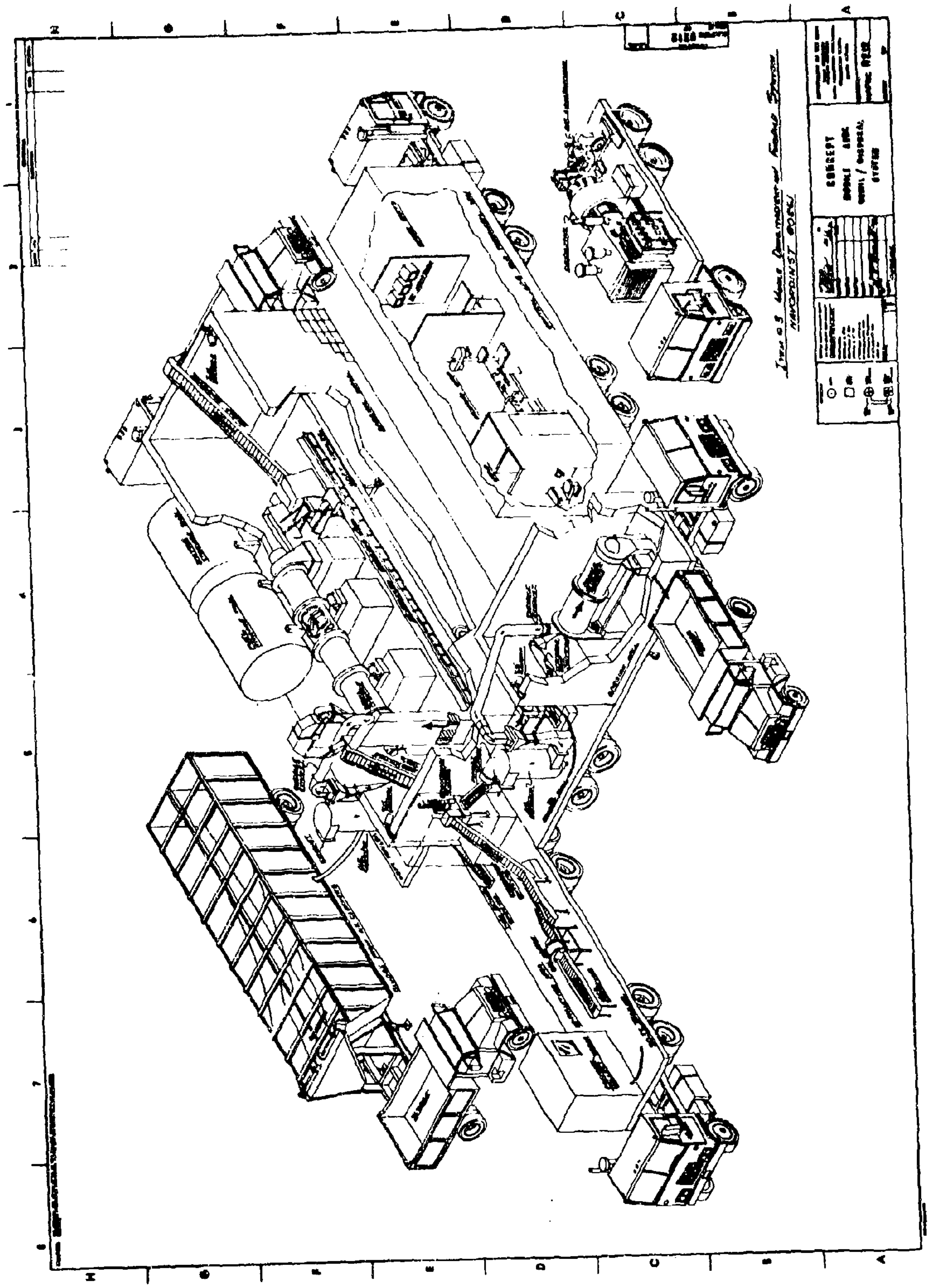
Demolition Grounds

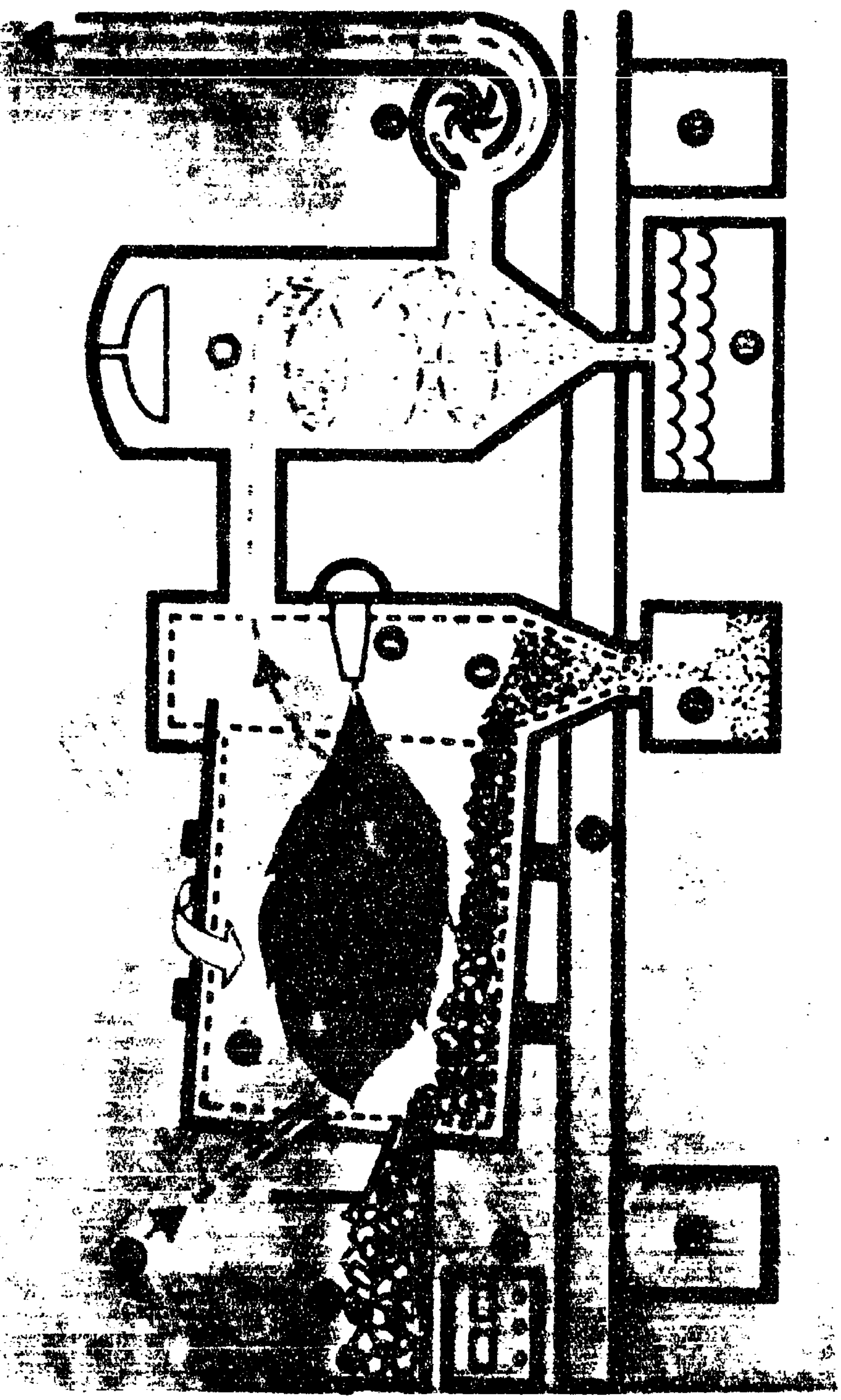
16" Projectile & Rockeye



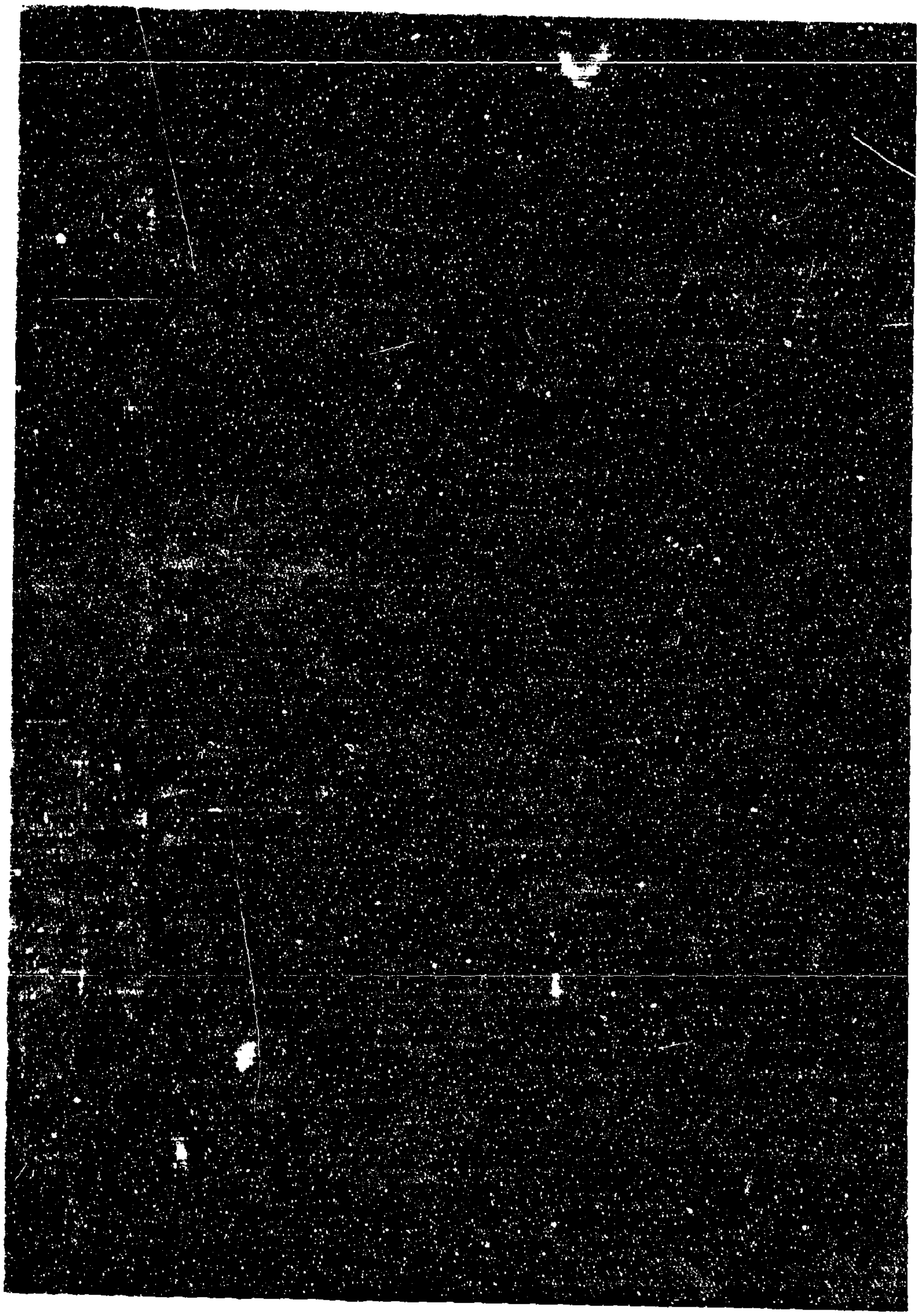
Earle Facility


URE OPERATIO





Commercial Incinerator

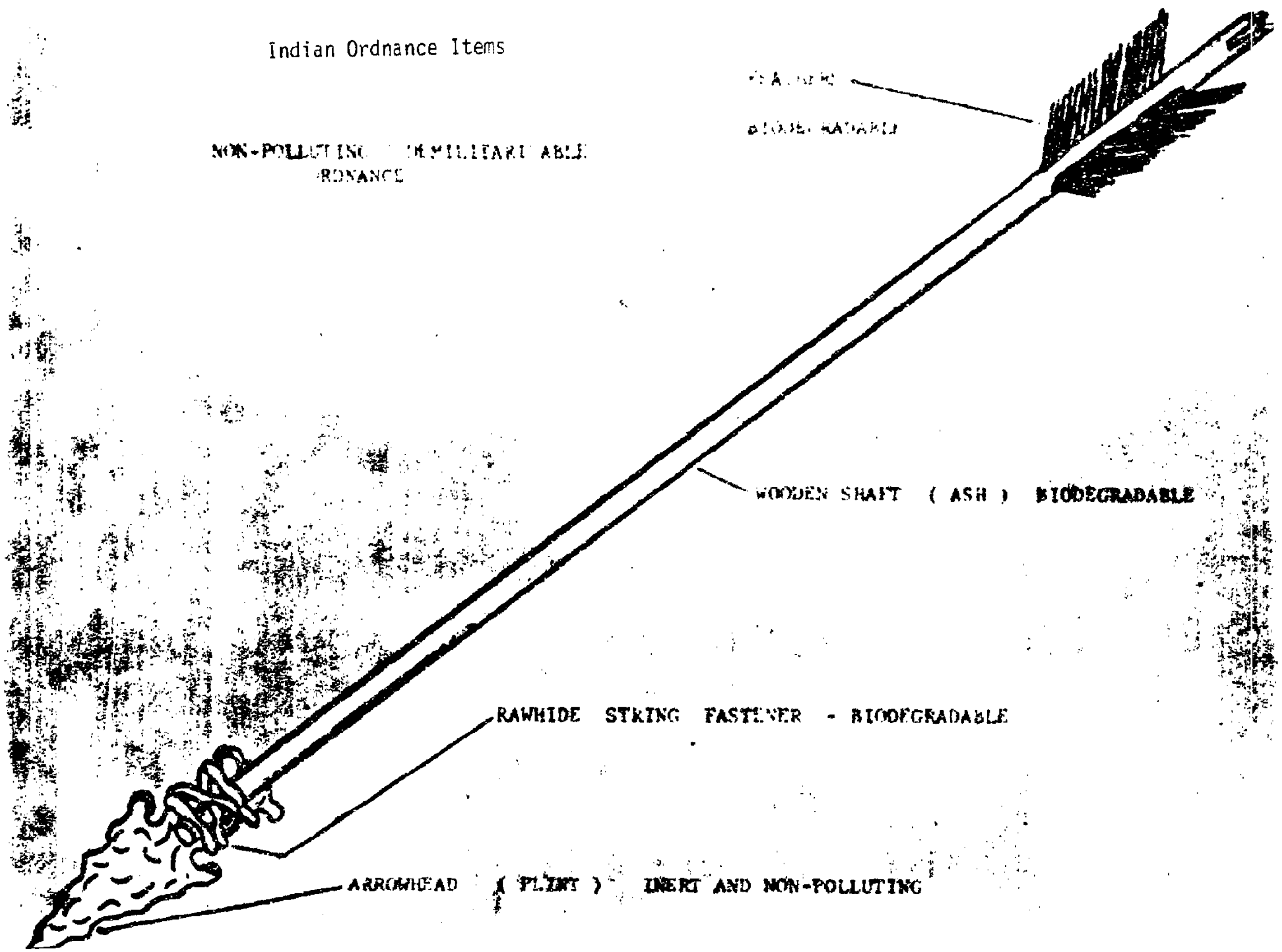


ALTERNATIVES TO RECYCLING AND SALVAGE

- CONTAINED DETONATION AND INCINERATION
- REMOTE DETONATION

Indian Ordnance Items

NON-POLLUTING DEMILITARIZABLE
ORDNANCE



DESIGN FOR DEMIL OF WEAPONS AND WEAPON SYSTEMS

EXPLOSIVE

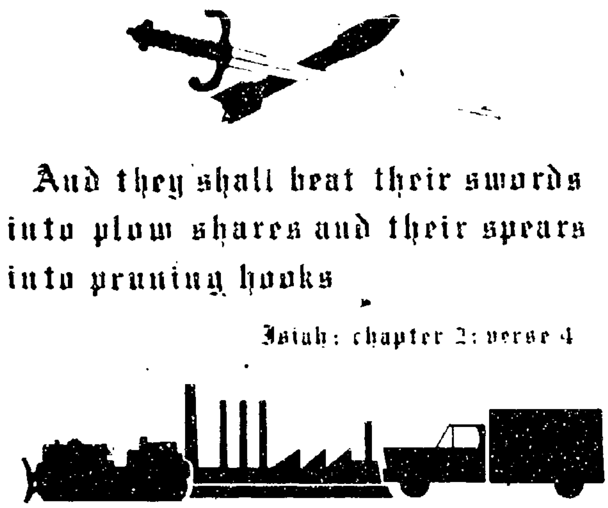
- BINARY EXPLOSIVE
- BIODEGRADABILITY
- DISPOSABILITY

COMPONENTS

AMMUNITION DISPOSAL

PRESENTED BY:

F. H. CRIST
CH, AMMUNITION EQUIPMENT OFFICE
TOOELE ARMY DEPOT
TOOELE, UTAH

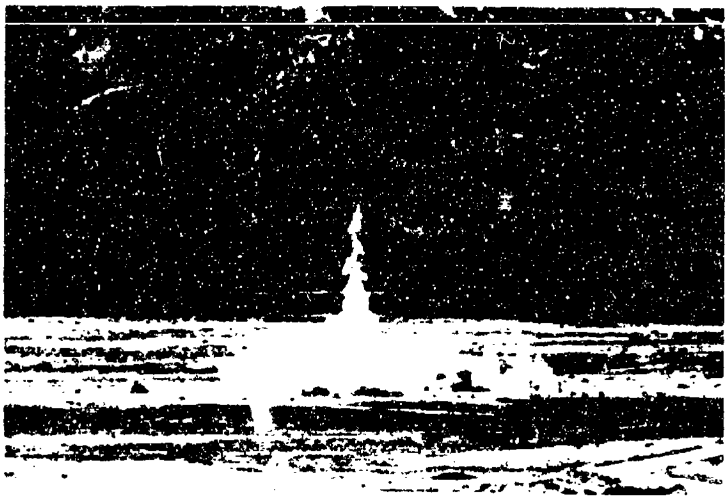


SLIDE #1

This slide illustrates the fact that demilitarization of excess or obsolete munitions is not a new problem. The task of demilitarizing sophisticated modern munitions is, however, a bit more complex than David's return of Saul's suspenders and flinging the unused pebbles into the river. The increased public interest in the preservation of man's natural environment has caused the Army to take a hard jaundiced look at its ammunition demilitarization methods and plan changes to correct deficiencies.

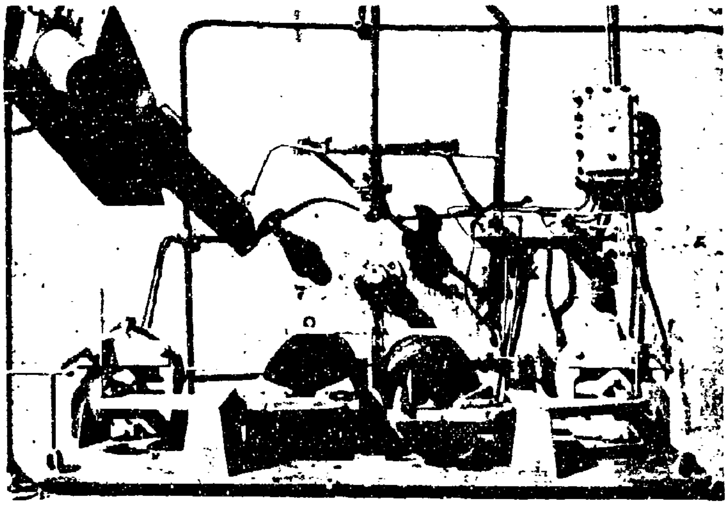
SLIDE #2

These billowing clouds of smoke frequently punctuated by unscheduled detonations typify the burning ground destruction of ammunition. Obviously, in spite of this being a very economical approach to the demilitarization of munitions, it is a very poor candidate method to implement President Nixon's EO 11507, which charges the Federal Government to set the example in the abatement of pollution to man's environment.



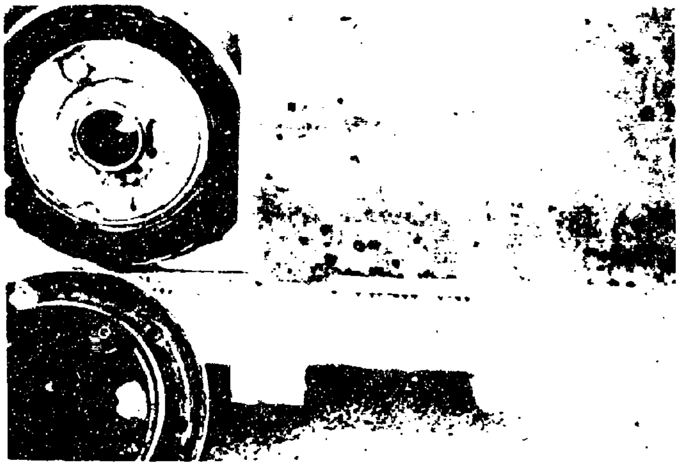
SLIDE #3

The ground and air shock attendant with the demilitarization by detonation, as depicted in this slide, has never won a military installation any popularity contests from its surrounding communities. Stringent maximum limitations in effect now for several years at installations in close proximity to population centers have greatly impaired the usefulness of this method for wholesale demilitarization.



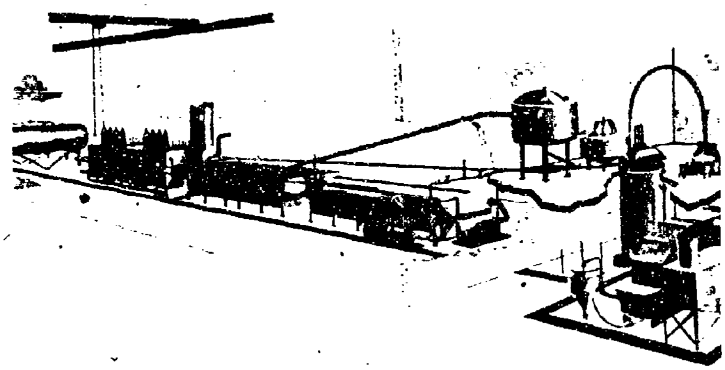
SLIDE #4

Design and development of several equipment systems for the disassembly and inerting of artillery projectiles and bombs was initiated by the Army to demil excess or obsolete munitions at the end of World War II. Specifically, this is the main barricade that shields operators from the physical disassembly of bombs, or large projectiles preparatory to washout of explosive filler. Note that closed circuit TV is provided for operator surveillance of the operation. A gravity type deluge system is also provided in the event a fire is initiated by the disassembly procedures. The equipment depicted here physically breaks the base assembly simultaneously from two (2) 750 lb. M117 series bombs. Only minimal manual disassembly need be performed prior to the beer opener type break-off of the base plate.



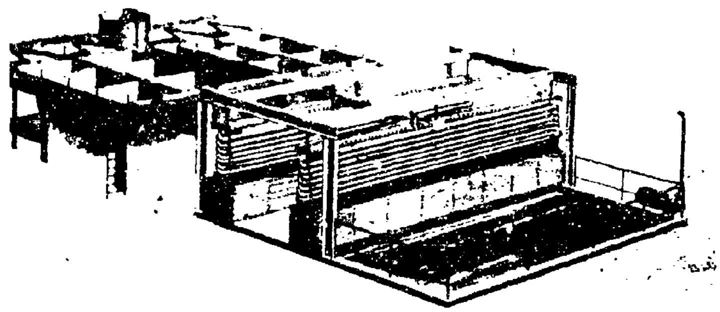
SLIDE #5

This slide shows a 750 lb. bomb with the base removed and the wax pad exposed. The wax pad is removed at the Washout Plant by hand tool assisted steam out procedures.



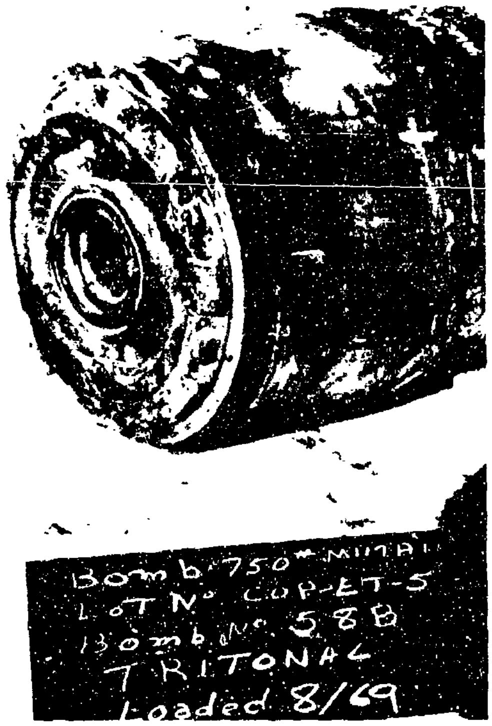
SLIDE #6

This artist's concept depicts the explosive washout and recovery facility. The system employs the use of hot water under pressure to melt and hydraulically mine the explosives from the shell or bomb body. One inherent disadvantage of this method lies in that the melting process somewhat distorts the basic composition of binary explosives. This results in a recovered explosive with a slightly different formula than when it was loaded into the munition. Generally, this means the recovered explosives are suitable for resale as a commercial blasting agent but is not entirely suitable for recycling into the manufacture of new explosives. To offset this, new techniques are being explored by which explosives can be removed from items using a minimum amount of water under relatively high pressure. To date, however, there has been no criticism of the current method because there is no contamination to the atmosphere or ground in the vicinity of the facility.



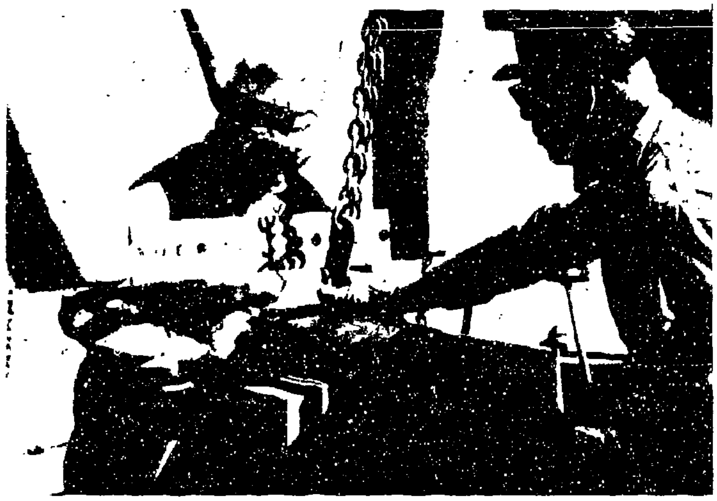
SLIDE #7

This artist's concept illustrates the system utilized to clean the effluent water for its continuous reuse in the washout process. No contaminated water is released from this system to contaminate the ground or underground water shed. Residue precipitated in the holding tanks and the effluent filters are removed and destroyed by burning. A furnace with scrubber will be required to avoid air pollution.



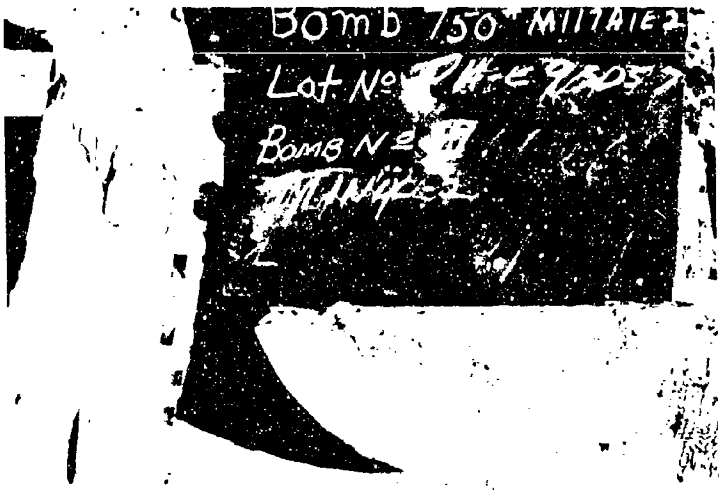
SLIDE #8

This slide depicts the exterior of a new type totally sealed 750 lb. bomb. New one-piece construction and bomb assembly with special thread coatings virtually precludes entry into the bomb using conventional disassembly methods.



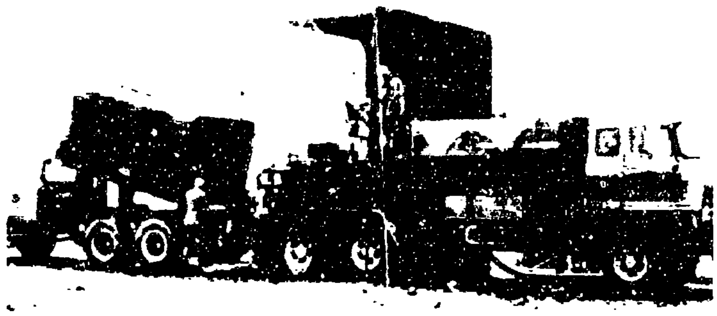
SLIDE #9

A requirement to visually and chemically inspect the interior of loaded bombs resulted in the development of a method to section bombs utilizing a standard industrial hac' saw. This slide depicts operator removing part of a bomb from the 'ter completion of a cut. No coolant or lubricant is used in rocess. Selection of the proper saw blades and control of cutting race is considered to be very essential to the relative safety of this operation. To date nearly 800 each munitions ranging in size from 500 lb. MK82 to 3000 lb. H6 loaded M118 bombs have been cut into 3 to 5 pieces. Explosive loadings in bombs have included TNT, Amatol, Tritonal, Minol II and H6.



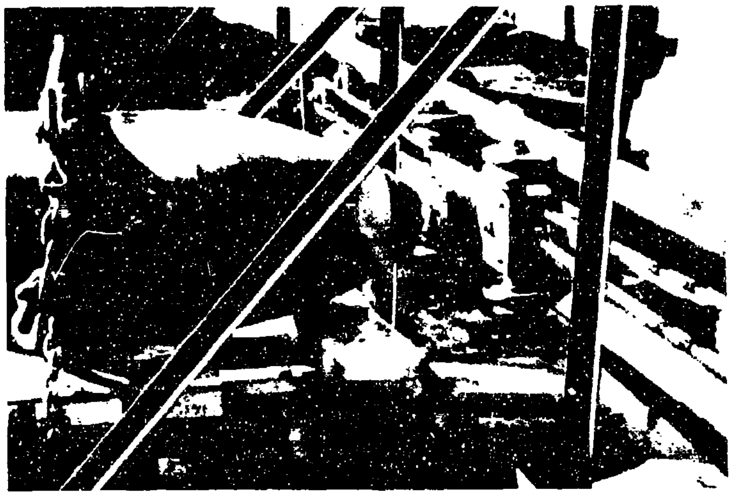
SLIDE #10

This view shows the interior of a new type 750 lb. bomb after sectioning. Threaded joints exposed here were coated with lock-tite prior to assembly.



SLIDE #11

The equipment depicted on this slide is normally used for water jet drilling of extremely deep oil wells. The truck on the right has a 1500 HP pump capable of producing 300 gallons per minute of water at 5,000 lb. per square inch pressure. The vehicle on the left provides sand that is added to the water to enhance the cutting or abrasive action of the water.



SLIDE #12

To test the feasibility of demilling bombs using the water jet method or hydro-knife method, a bomb previously sectioned in a saw was secured so that the water jet attacked the fuze well liner in its nose end. This slide shows bomb section positioned for the test.

SLIDE #13

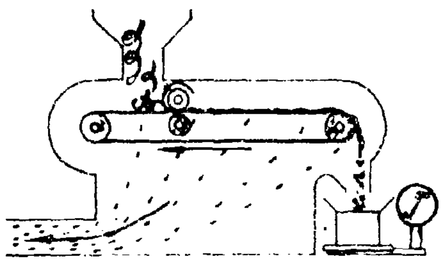
This slide depicts the results of eight (8) minutes of water jet erosion. Fuze well liner was defeated and the jet quickly cut through the core of the explosive filler. Water pressure for this test was 3500 PSI at a flow rate of 300 GPM, 3/4 lb. of sand was added per each gallon of water. This technique has much to offer in the demilitarization of ammunition and should be explored to obtain maximum utilization of its' potential.

SLIDE #14

A combination of the sawing method to expose the explosive filler and the application of an extremely high pressure and low volume water jet (hydro-knife) should provide a very acceptable and efficient means of downloading munitions. The water jet erosion of the explosives is not expected to degrade any standard explosive that would prevent its recycling in the manufacture of new munitions.

PROJECT "HYDRO-KNIFE"

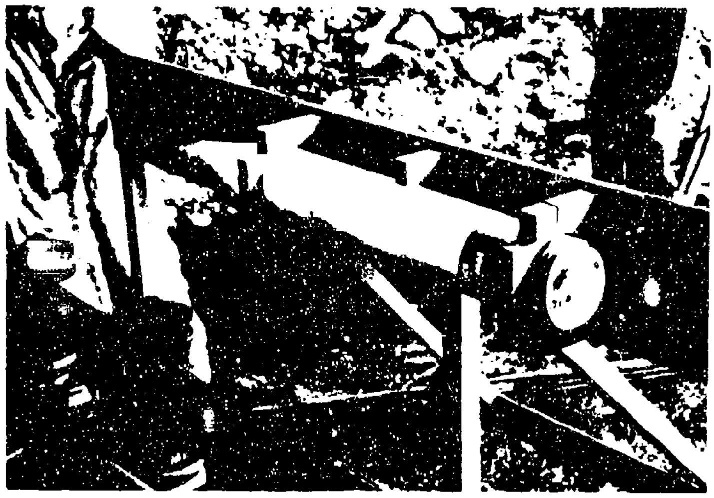
VI



EXPLOSIVE REDUCTION, DRYING AND PACKAGING.

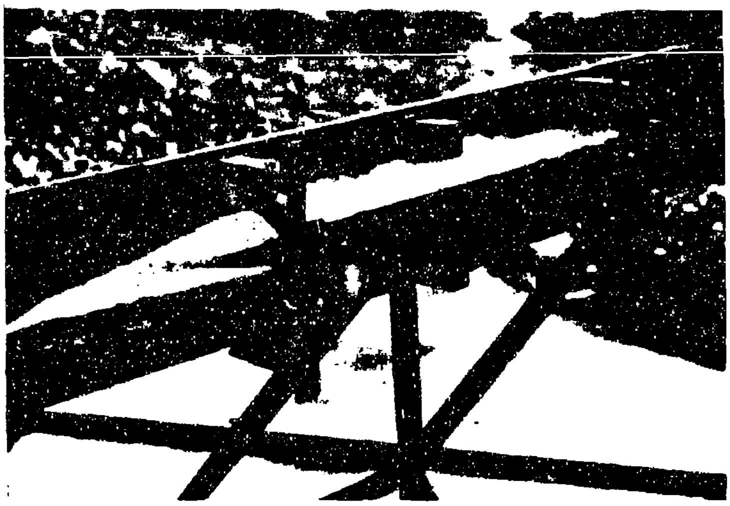
SLIDE #15

Since a relatively small amount of liquid will be required to effect explosives removal, the drying and recovery process will be accomplished in a relatively simple apparatus. The explosives recovered should be acceptable for recycling without further rework.



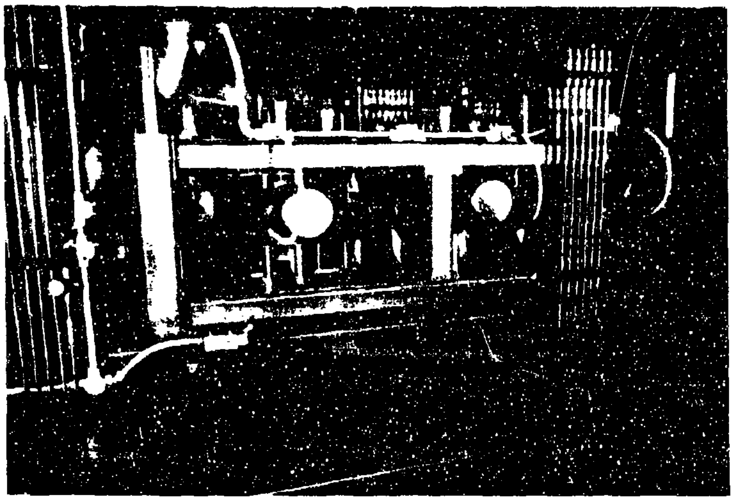
SLIDE #16

Another potential application of the sand enriched high pressure water jet is to gain access or demilitarize thin cased difficult or dangerous to disassemble munitions. In this test an M61 rocket warhead was attacked with 3500 PSI sand enriched water.



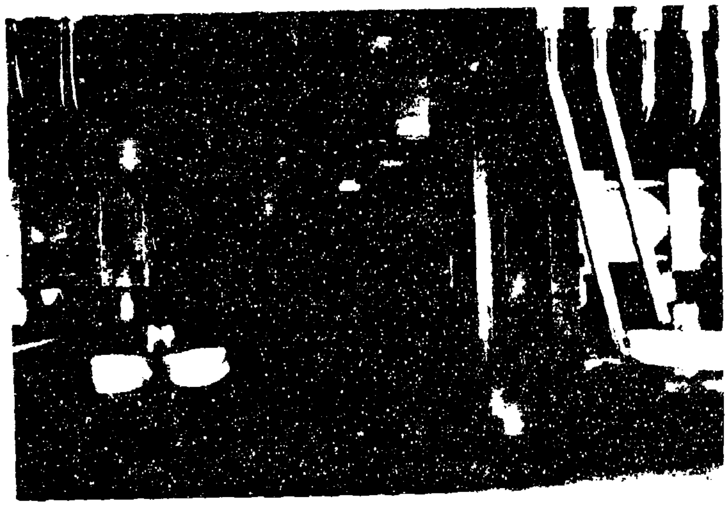
SLIDE #1

In 5 minutes the water jet cut through all metal components, into both bursters and removed 95% to 98% of the Comp B., as well as the RDX booster from the fuze.



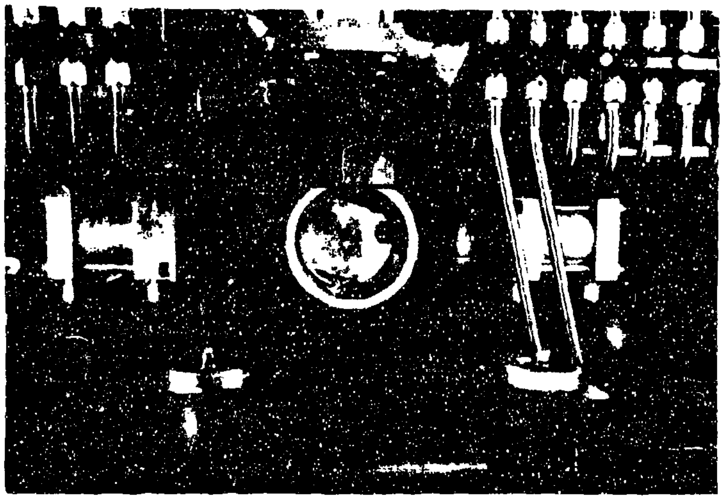
SLIDE #18

This machine was developed for the demilitarization of a large quantity of rocket ammunition. Complete rockets, in their shipping containers, are automatically fed into the machine, clamped at 6 places, submerged under a liquid and then sawed into 7 pieces.



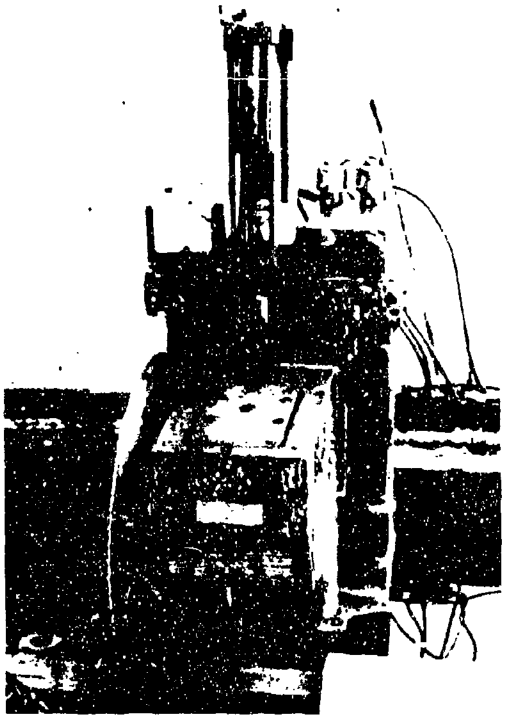
SLIDE #19

This view shows the six pair of apposed clamps that receive and grip the rocket in its shipping container. Note the circular saw blades in position to part the rocket into seven pieces.



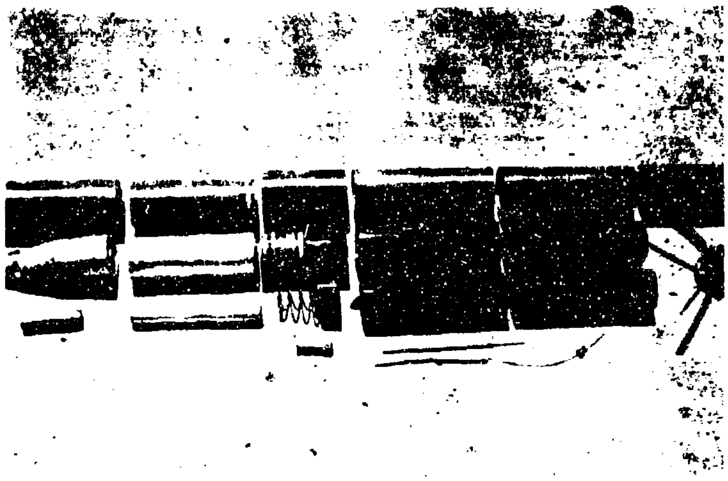
SLIDE #20

Here the rocket, in its container, is clamped ready for submerging into the liquid bath and demilitarization by sawing.



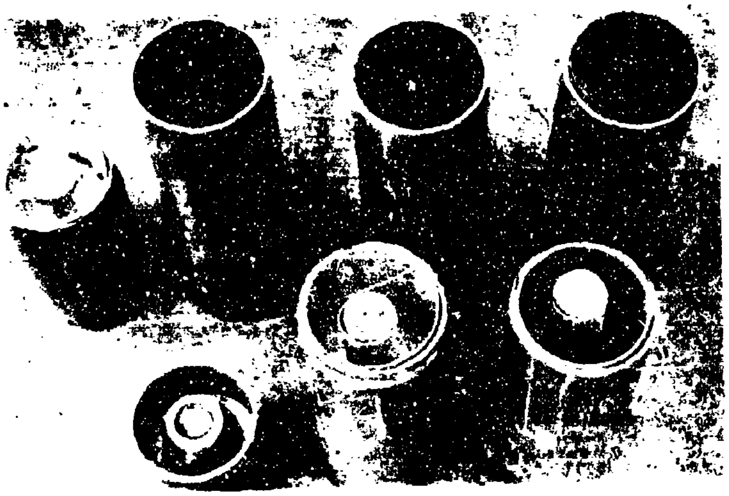
Slide #21

This equipment represents a radical departure from conventional disassembly techniques. Six commercially available cold saws part the munition, in its shipping container, into seven pieces. The special 16" diameter cutting blade is driven at 22 1/2 RPM. Approximately 40 seconds is required to cut through the 5 inch diameter work piece. Several hundred dry cuts through live munitions without incident verified the relative safety of this procedure. The safety aspect has been further improved by submersing the work piece in liquid on the production machine. This slide depicts a cold saw in the process of a test cut through a submerged rocket during the machine development.



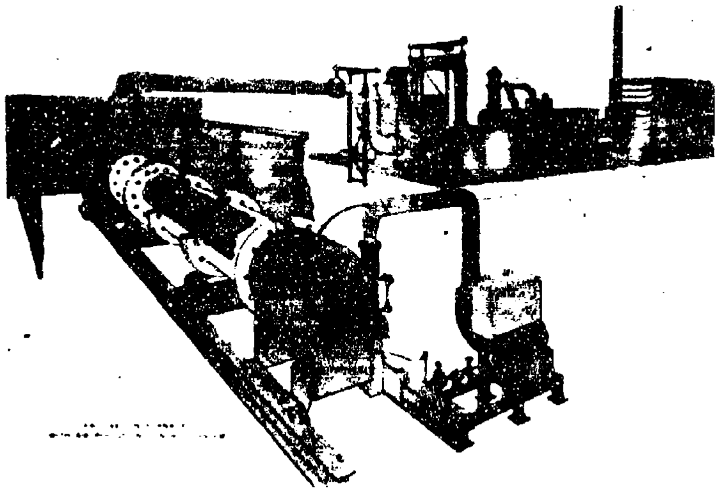
SLIDE #22

This rocket has been cut at 6 places, thus completely disassembling the entire rocket system. Note that the use of the saw method eliminates the need for unpacking.



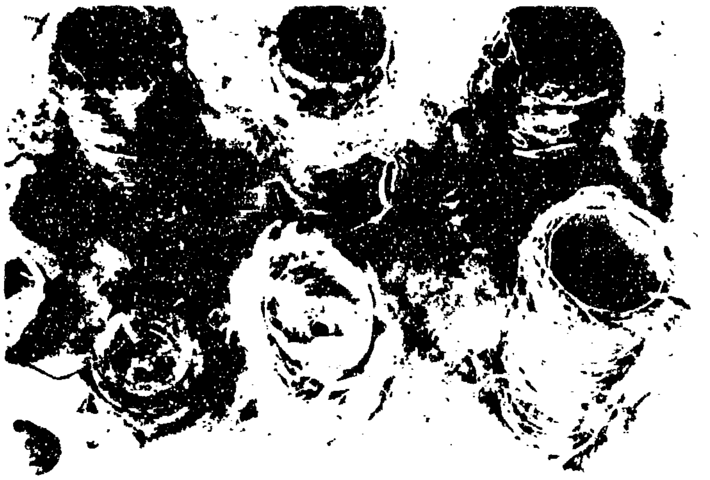
Slide #23

This view shows the cuts that have been made through the propellant including the unsupported resinator rods, RDX fuze booster and Comp B burster.



SLIDE #24

Cut up rocket sections are fed into the deactivation furnace, depicted by this artist's concept. Spiral flights cast as an integral part of the 20 ft. long, 4 ft. diameter oil or gas fired retort provide separation of the components through the furnace and residence time adequate to insure thorough decontamination. The effluent treatment and scrubber system, shown in the background, removes particulate loadings and noxious gasses or by products from the effluent.

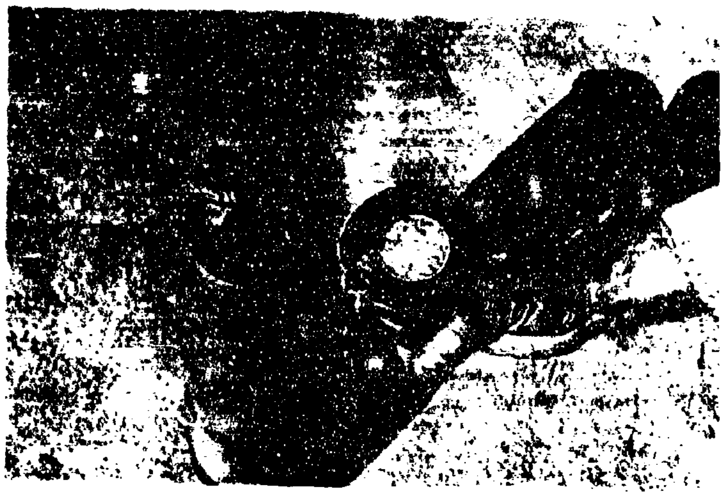


SLIDE #25

After a predetermined residence time and temperature in the furnace, the inert rocket components are discharged from the furnace. This slide depicts the inerted residue generated by the deactivation furnace.

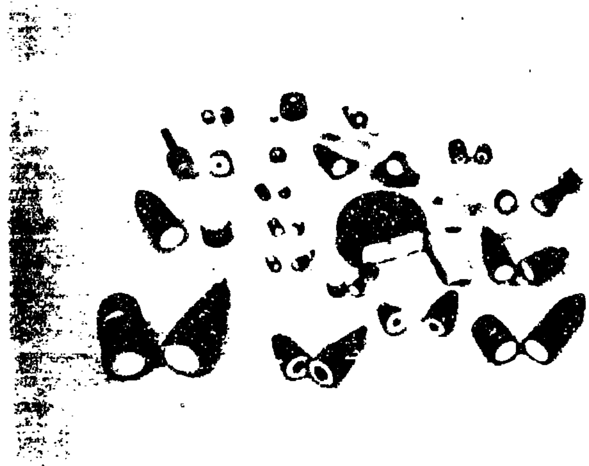
SLIDE #26

The use of the cold saw technique used in the demilitarization of the rockets has been broadened to include exposing of the explosives in the fuze burster assembly of projectiles. This procedure is being considered in lieu of normal disassembly methods.



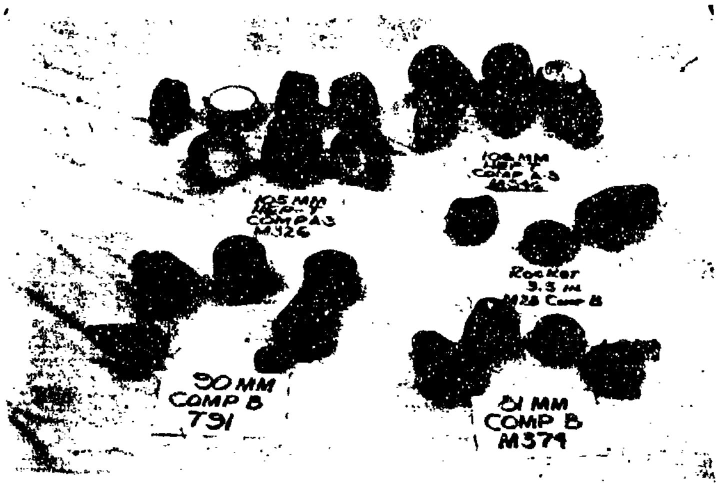
SLIDE #27

This slide shows the very sensitive fuze components successfully parted utilizing the cold saw. Cutting of these components was accomplished without submersion of the projectile in liquid. Saw blade life and operational safety will be enhanced by provision of a liquid bath in the application of this method for a production machine.



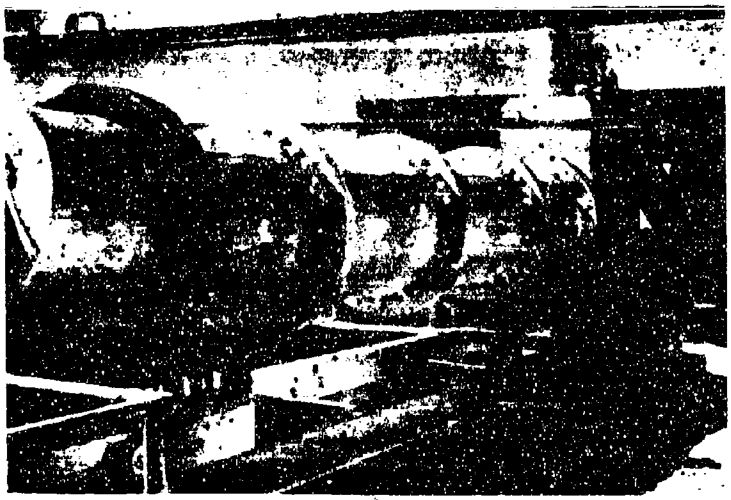
SLIDE #28

Many types of artillery shell, rockets, mines, grenades, etc., have been cold saw sectioned to expose their H.E. filler. Several candidate methods of explosive removal are now being evaluated. These methods include burning in the deactivation furnace, removal by high pressure water jet, ultrasonics microwave heating or chemical extraction and recovery.



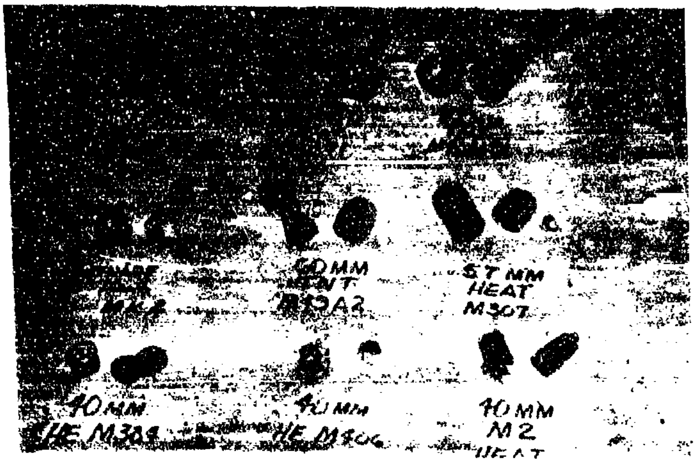
SLIDE #29

Several of the items identified on the previous slide have been further reduced in size prior to their introduction into the deactivation furnace. The larger items were cut two or more times to reduce the amount of explosives in each section to one and one half pounds or less. It may be noted that all fuze assemblies were cut through the booster area while they were in the projectile.



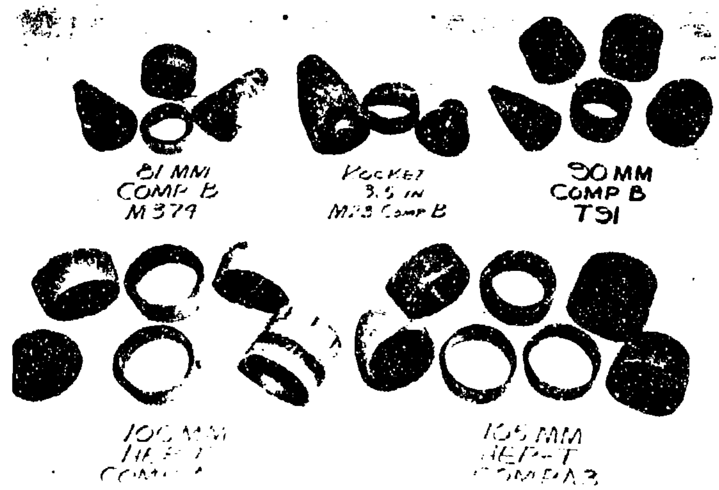
SLIDE #30

Sectioning of the munitions to expose their explosive content permits their burnout rather than the normal occurrence of inducing a controlled detonation in the deactivation furnace. This photo depicts the deactivation furnace utilized in these tests.



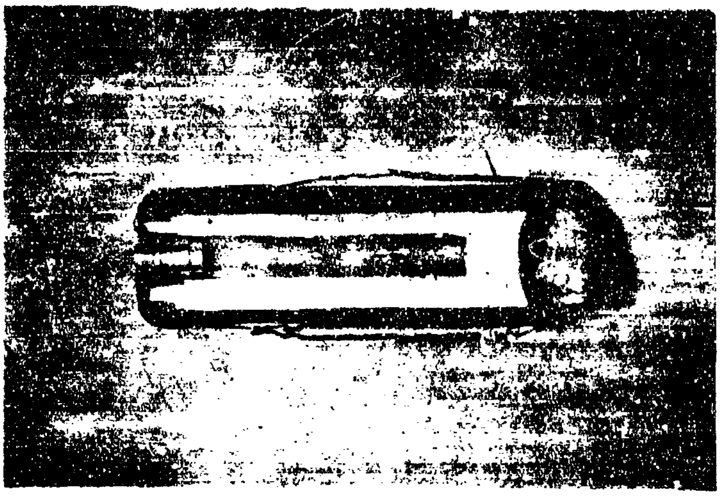
SLIDE #31

Burnout offers three distinct advantages over the controlled detonation procedure, these being: increased production capability, prolonged furnace life, and greater efficiency in scrubbing exhaust emissions.



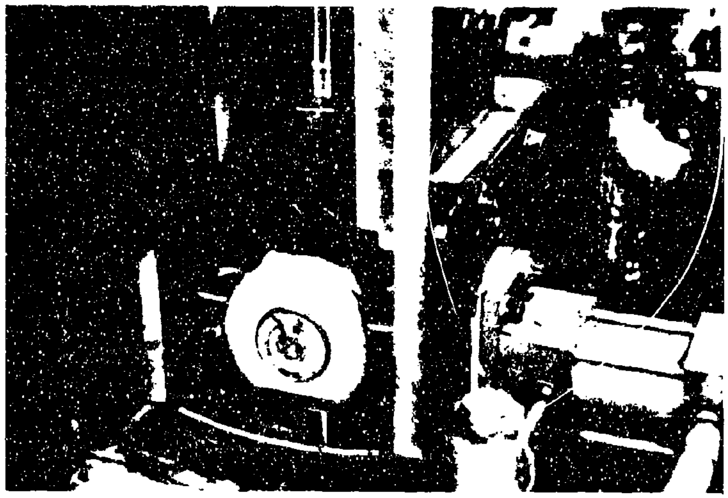
SLIDE #32

Tests indicate that ammunition items can be burned out in the deactivation furnace in pieces larger than those depicted on this slide, providing the fuze booster assembly has been cut. Presently the size of the sectioned item that can be introduced into the furnace is limited to the size of the furnace feed opening.



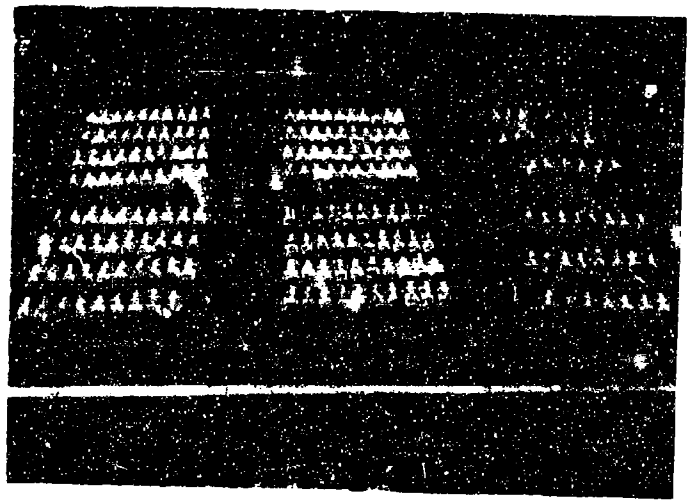
SLIDE #33

We were recently frustrated in every effort to remove an aluminum fuze from this bomblet. The problem was finally resolved by the design of a shear that drove a pointed flat punch through the top of the casing aft of the fuze to shear the encased tetryl burster.



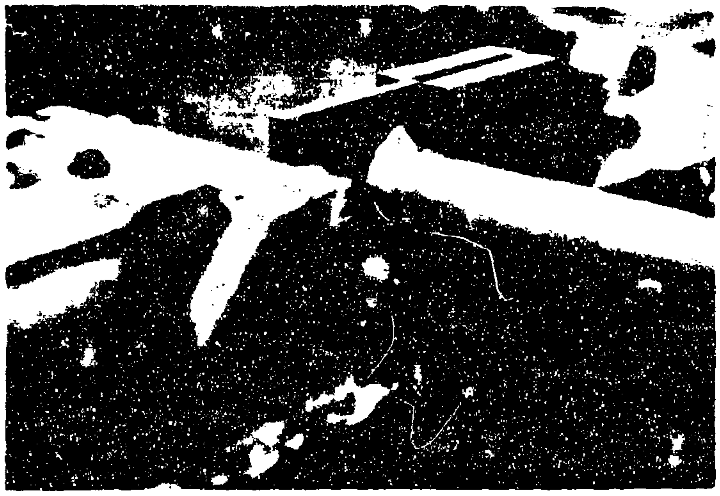
SLIDE #34

This slide depicts the burster shear apparatus used during bomblet demil operations to expose the explosive components prior to introduction into the deactivation furnace.



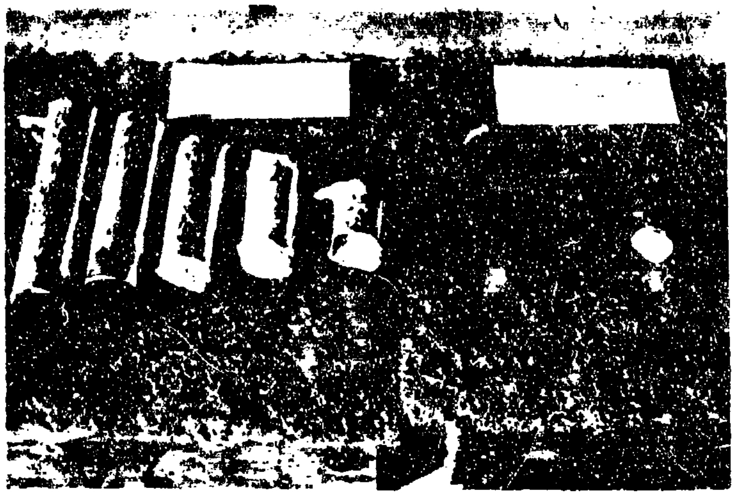
SLIDE #35

This slide represents a sample of the many bomblets that were demilled in this manner during test operations. Note that exposure of the burster explosives facilitated burning rather than detonation in the deactivation furnace.



SLIDE #36

Exposure of the explosive to burning has been accomplished using the saw as mentioned above, also we have experimented with booster and burster shearing. Shearing is accomplished by severing the explosive component with a round or flat punch like apparatus.

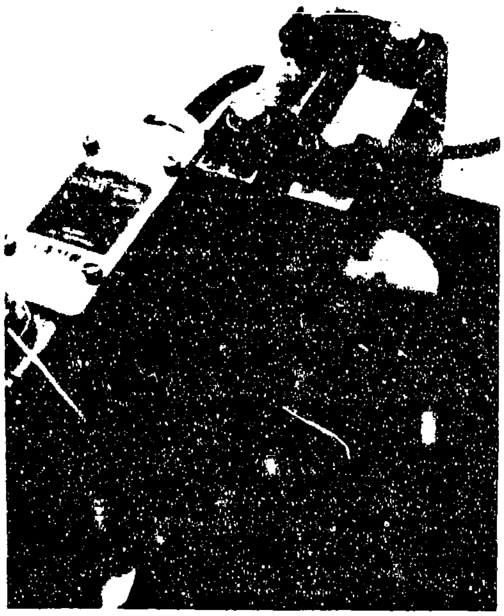


SLIDE #37

This is a sample of the many types and sizes of bursters that have been reduced in size preparatory to their introduction into the deactivation furnace. We have not experienced any detonation of items thus prepared before introduction into the furnace.

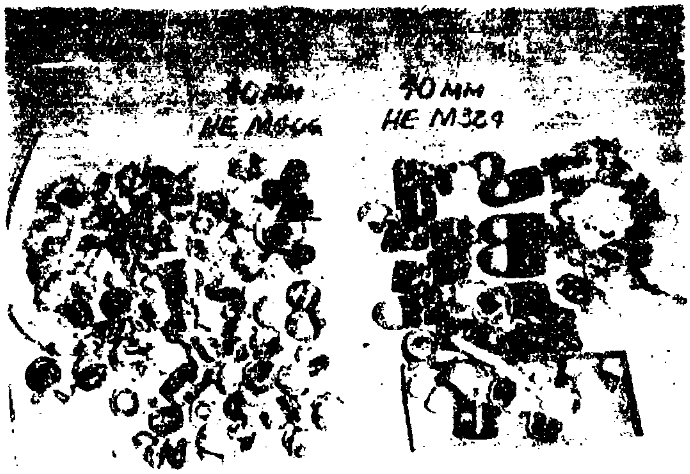
SLIDE #38

40MM, M384 and M406 cartridges have also been sheared. Tests indicate that complete shearing of the round into separate sections is not necessary. Cutting into the item to a depth of 5/8 inch exposed the explosive to where the cartridge burned acceptably in the furnace. Note that this procedure does not include any disassembly operations.



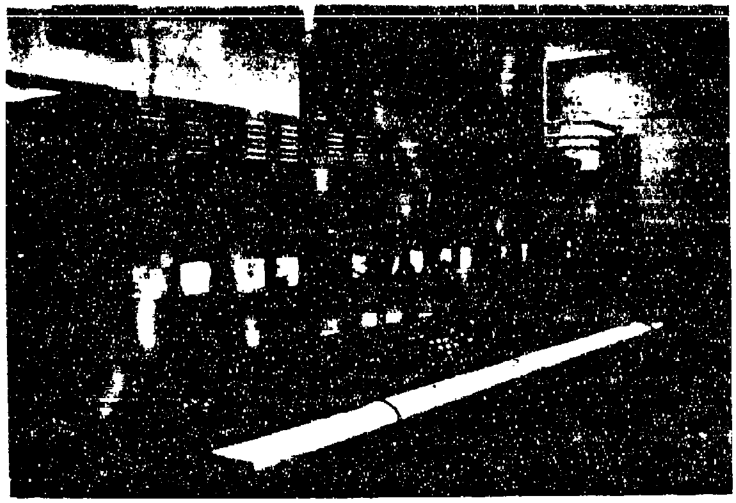
SLIDE #39

On some rounds, the link assembly caused minor problems in shearing since it is located in the area thought to be the most desirable to penetrate. Continued testing indicated that precise location of the penetration is not critical to the controlled burning process.



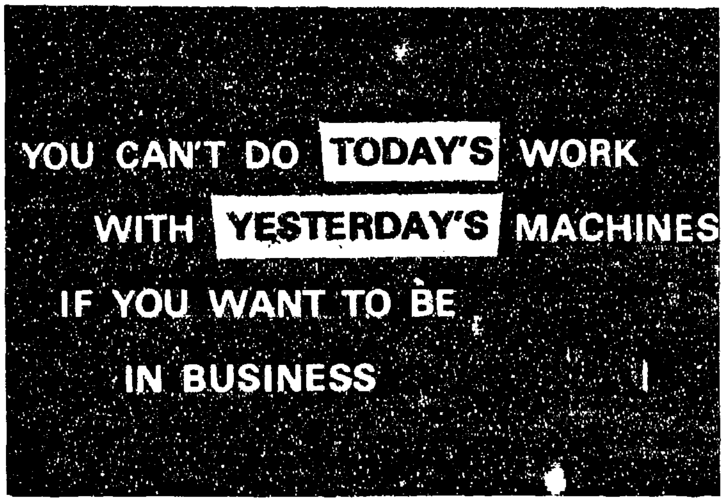
SLIDE #40

This slide depicts a sample of the 40MM cartridges processed through the furnace. Variance in appearance between the M384 and M406 residue is a result of changes in furnace operating temperature in an attempt to select operational conditions that would guarantee decontamination and still produce salvageable scrap.



SLIDE #41

Production demil operations utilizing the saw or shear methods will be controlled and monitored at remote control consoles such as this module provided at one of our demilitarization operations.



SLIDE #42

You Can't Do Today's Work with Yesterday's Machines If You Want To Be In Business Tomorrow.

SHOCK ATTENUATION DESIGN FOR THE DUCTING OF AN EXPLOSIVES DEMILITARIZATION FURNACE

by

Mr. Brian P. Bertrand
Ballistic Research Laboratory
Aberdeen Reseach and Development Center
Maryland

PRECEDING PAGE BLANK

Introduction

The BRL was asked to help establish shock loading inputs to be used as criteria for the shock resistant design of an explosives-destruction facility. Much information, such as shock attenuation methods, shock pressure vs distance, etc. is available in the literature (see references). Part of this problem required measurement of the shock pressure and duration at points that could be considered as input to be used for prediction for some presumed worst case.

The facility consists of a furnace (Figure 1) in which the explosives are exposed to high temperature flame as they advance through the furnace in groups of 7 charges of 0.55 lbs each. The gases given off during combustion are drawn through ducting for further processing. There is the possibility that if one charge detonates instead of burning, it might cause others of the six remaining in its group to detonate also. The resulting shock wave could possibly damage equipment in the processing line, so some prediction techniques, backed up by pressure measurements, had to be made, and an attenuation scheme developed. The sections that follow concern the part of the problem associated with the furnace and the ducting, in the following order.

1. Detonation of a charge in the furnace.

   a. Residual overpressure in furnace.

   b. Shock pressure measurements in the furnace , and in the exhaust duct.

   c. Calculation of equivalent shock tube driver energy ratio , based on calculated residual pressure and measured shock pressure at point E.

   d. Predicted shock pressure for 1, 2 and 7 charges based on 1.c above.

2. Attenuation methods in ducting.

1. Detonation of Charges Within the Furnace.

The interior wall of the furnace has a helical shape, so that by rotating the furnace the charges are gradually advanced toward the

furnace exit and are subjected to higher temperature as they go. It is expected that, if detonation instead of combustion occurs, it will happen when the charge is between location 1 and 2 (Figure 1) so the ducting was instrumented with pressure gages at the points shown, and charges were detonated at locations 1 and 2. The charges were either 0.55 or 1.10 lbs of tetryl.

a. The residual pressure within the furnace after the detonation (assuming a closed furnace) can be calculated approximately by the relation (Ref. 1)

$$\Delta P = \frac{4000\,hW}{V} \qquad \text{Eq. 1}$$

where h = 2.9K cal/gm (heat of combustion)
W = weight of explosive, lbs.
V = volume of furnace, about 100 ft^3

This calculation results in the following:

Charges	Weight lbs	ΔP psi
1	0.55	66
2	1.10	132
7	3.85	482

These values of residual pressure are conservative since they assume complete combustion.

b. The pressure records (Figure 2) are consistent within each shot, but vary somewhat over the range of shots. The loading within the ducting, at points E and F, determine what will be transmitted throughout the rest of the duct. The highest mean pressures observed at E and F are near 10 psi for 1 charge and just under 20 psi for 2 charges, where the charge location was 5-1/2 feet from the end of the charge chute. The wave duration at point E averages about 30 milliseconds. The duration at F is less because of the relief that occurs at the opening just about point F. The reflected and stagnation pressures observed at A are consistent with the pressure at F.

The pressure measured at C is characteristically a shock of 22 psi fo owed by the residual pressure 2 millisecoı ıs ıater to the 50-80 psi region for 1 charge. The records here are noisy, probably due to mounting motion and to transverse waves from multiple shock reflections within the furnace.

Pressure at point D is highest, of course, for charge location 2; the gage is in the stagnation position and also gets some reflected component from the floor surface. The overpressure duration is generally a little less than in the ducting of E, but it appears that about half of the energy resulting from detonation within the furnace would find its way through this exit.

Pressures at G and H are around 1/2 psi, so there's no significant leakage through the flange clearances.

c. We can now consider the furnace to contain gas at the calculated residual pressure and assume that the furnace acts like a shock tube driver. The relationship between driver pressure, shock pressure and energy ratio between the gases in the driver and driven sections of a shock tube is:

$$\frac{E_1}{E_4} = \left(\frac{2\gamma_1}{\gamma_1 - 1}\right)\left(\frac{\gamma_4 + 1}{\gamma_4 - 1} \quad \frac{P_2}{P_1} + 1\right)\left[\frac{\left(1 - \left(\frac{P_1}{P_4}\right)\left(\frac{P_2}{P_1}\right)\right)^{\frac{\gamma_4 - 1}{2\gamma_4}}}{\frac{P_2}{P_1} - 1}\right]^2 \qquad \text{Eq. 2}$$

where P_1 = ambient pressure, psia

P_2 = shock pressure, psia

P_4 = driver pressure, psia

γ = ratio of specific heats

E_1 = internal energy of gas in driven section

E_4 = internal energy of gas in driver section

The highest shock pressure measured in the duct at point E resulting from the detonation of 1.10 lbs (2 charges) at location 1 was 20 psi. The average of 5 shots was 16 psi. Using the higher value,

$$\frac{P_2}{P_1} = \frac{20}{14.7} + 1 = 2.36.$$ The calculated residual pressure for 2 charges is 132 psig, so $$\frac{P_1}{P_4} = \frac{14.7}{132 + 14.7} = 0.1.$$

Assuming that $\gamma = 1.4$ and entering Eq. 2 with these values of P_2/P_1 and P_1/P_4, the energy ratio is $\frac{E_1}{E_4} = 2$.

d. Based on this effective energy ratio, the prediction for shock pressure at E from 1 charge and from 7 charges are made and summarized below:

No. of Charges	Weight	Calculated residual Pressure	Predicted Shock at E	Highest Measured Value	Average Measured Value
	lbs	psi	psi	psi	psi
1	0.55	66	11	10	8
2	1.10	132	20	20	16
7	3.85	482	34	-	-

The calculated and the measured value of shock pressure at point E for 1 charge show reasonably good agreement, so it is assumed that the predicted value for 7 charges is good and can be used with confidence. Now the problem is to reduce the shock wave in pressure from the value calculated at E as input to a low enough value that damage will not occur later in the ducting.

We use as inputs at E the following:

Charges	Shock Pressure	Duct Diameter	Wave Duration
	psi	ft	msec
1	10	2	30
2	20	2	30
7	34	2	30

2. Attenuation Methods in Ducting

The shock wave transmitted through the duct can be reduced in strength in several ways.

Very long ducting.

Increased duct diameter following the initial 2' diameter.

Baffled sections of ducting.

Dump tank (expansion into large volume).

a. The first way is not very effective (Ref. 2). For example, if there was a shock of 10 psi traveling through a 2 foot diameter duct, and the wave had a positive pressure duration of 30 milliseconds at a point at the beginning of the duct, then after 54 feet of travel the shock wave would have been reduced to about 8.9 psi (these figures are for maximum pressure we expect for 1 charge).

b. Duct area increase is an effective method for reducing the shock overpressure. Figure 3 is a graph of transmitted shock pressure versus area ratio. There it can be seen, for instance, that the pressure may be reduced a factor of 2 by increasing the diameter by a factor of $\sqrt{3}$. It must be noted that these predictions are for distances beyond 5 diameters of shock travel in the larger duct.

c. Baffle sections are also effective for shock attenuation. Figure 4, from Ref. 3, is a plot of baffle dimensions versus attenuation factor. The use of spacing equal to tube diameter generally produces the most attenuation.

d. The use of a large volume dump tank will also reduce the shock significantly. It is essentially an area increase but is quite large in diameter. Experiments at BRL (Ref. 4) have shown that if one were to attach a duct of cross-sectional area A to a large tank of volume V, then a constant pressure shock traveling from the duct would fill the tank to shockpressure in a time of $\frac{V}{A}$ ft milliseconds. If instead, the input wave is short, then the tank pressure would not reach the maximum input shock pressure. The observed pressure in the tank would be a greatly weakened blast wave, followed by a gradual increase in pressure as the incoming shocked air fills the volume. Figure 5 shows how a combination of these methods could be used for the present problem. Figures 3 and 4 are used to determine the shock attenuation.

Sample Evaluation of Attenuator

Assume: 1 Charge , 0.55 lbs Tetryl

P_1 = 10 psi

Baffle sections consist of 2 pipes, 2 feet diameter, baffled every 2 feet for a distance of 40 feet, the baffle having holes of 1 foot diameter (Figure 5).

(1) From Figure 3, the shock pressure P_2 after expansion by area ratio of 2 in the 'Y', would be 6.5 psi. Then the wave reaches the baffle and propagates through it.

(2) From Figure 4, we find for $W = \frac{Z(D-D^1)}{D^2} = 10$, $Q = .08$

so P_3 (pressure following the baffle section) is $(0.08)(P_2) = 0.52$ psi.

(3) The expansion into the tank represents an area ratio of

$$\frac{8^2}{2\ (2^2)} = 8.$$ From Figure 3 the trend of attenuation indicates

the transmitted shocks are about 1/4 the input shock for area ratio 8, so the wave would decrease from 0.52 psi to about 0.15 psi in the tank.

The input wave is short (30 milliseconds). The $\frac{V}{A}$ is $\frac{8^2 \times 16}{2\ (2^2)} = 128.$

So the tank would fill to 0.52 psi at 128 milliseconds if the input shock were at a constant pressure of 0.52 psi for 128 milliseconds. The wave is only about 25% of that duration and is not constant in pressure, so the tank would reach only about 1/4 of that value, 0.15 psi.

Charges	P_1	P_2	P_3	P_D
1	10	6.5	0.52	0.15
2	20	13	1.04	0.26
7	34	23	1.84	0.46

Additionally, there would be some further attenuation due to distance traveled by the shock because of its decaying pressure-time profile.

References

1. Annals of the New York Academy of Sciences, Vol. 152, Art. 1, Prevention of and Protection Against Accidental Explosion of Munitions, Fuels and Other Hazardous Mixtures, October 1968, Page 313 - Petes: Blast Characteristics.

2. Oak Ridge National Laboratory TM 1750, Attenuation of Shocks in Tubes by Orifice Plates, Dresner and Chester, February 1967.

3. BRL Memorandum Report 1809, Attenuation of Peaked Air Shock Waves in Smooth Tunnels, G. A. Coulter, November 1966.

4. BRL Memorandum Report 1390, Information Summary of Blast Patterns in Tunnels and Chambers, 2nd Edition, Shock Tube Facility Staff, March 1962.

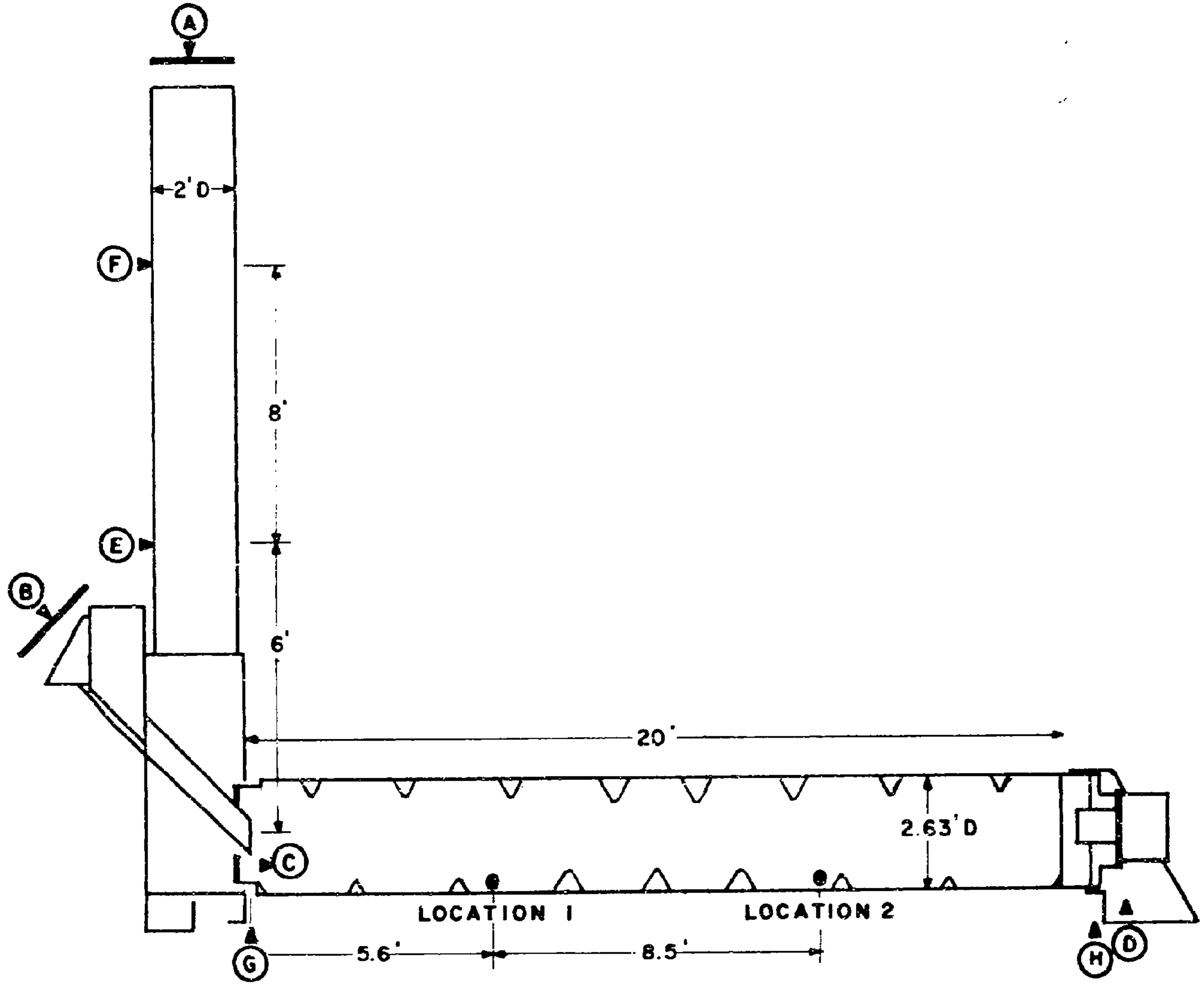


FIG. 1 FURNACE SHOWING CHARGE AND GAGE LOCATIONS

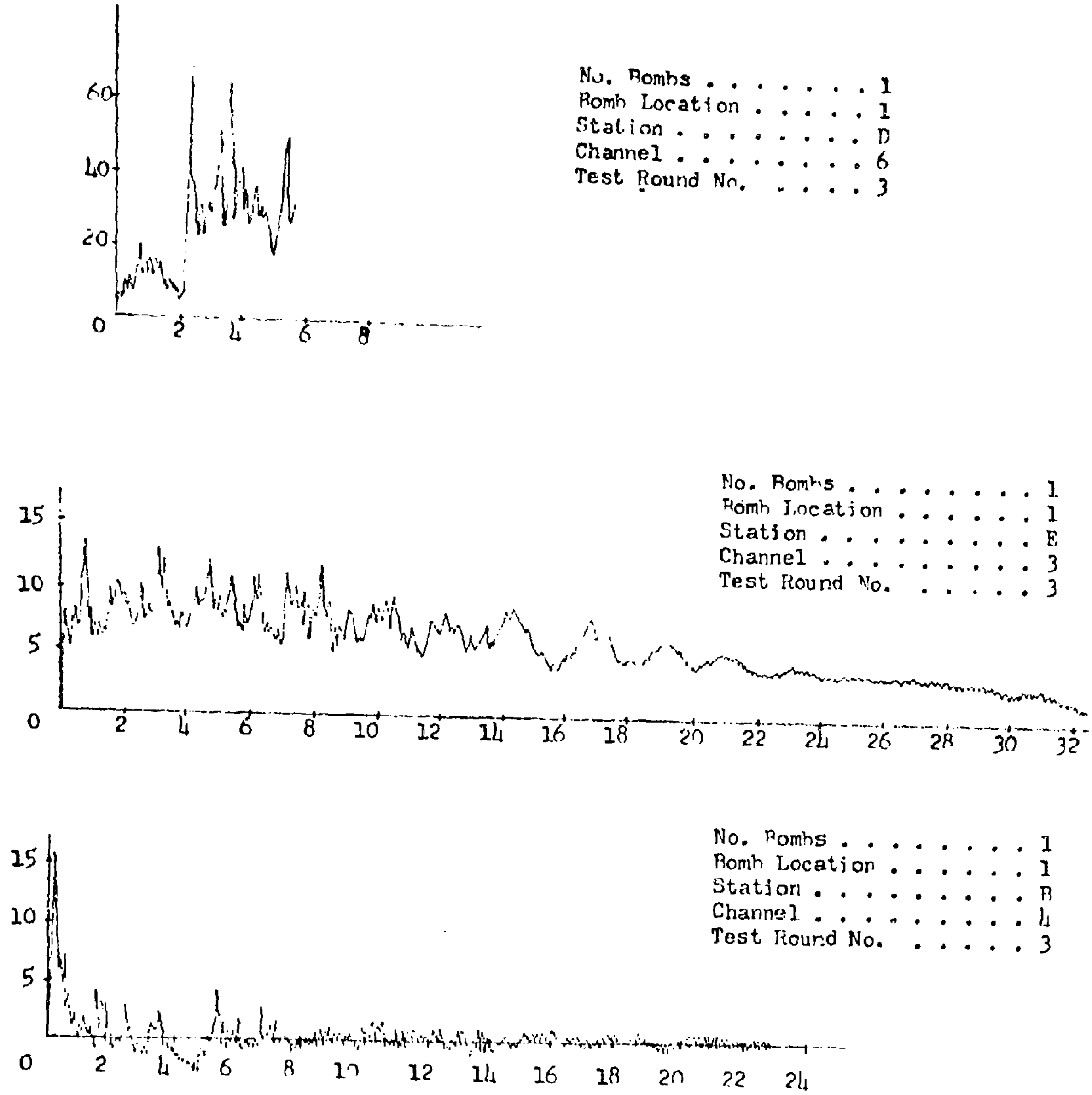

No. Bombs 1
Bomb Location 1
Station . . . . D
Channel 6
Test Round No. 3
No. Bombs 1
Bomb Location 1
Station . . . . E
Channel 3
Test Round No. 3
No. Bombs 1
Bomb Location 1
Station . . . . B
Channel 4
Test Round No. 3

FIG. 2

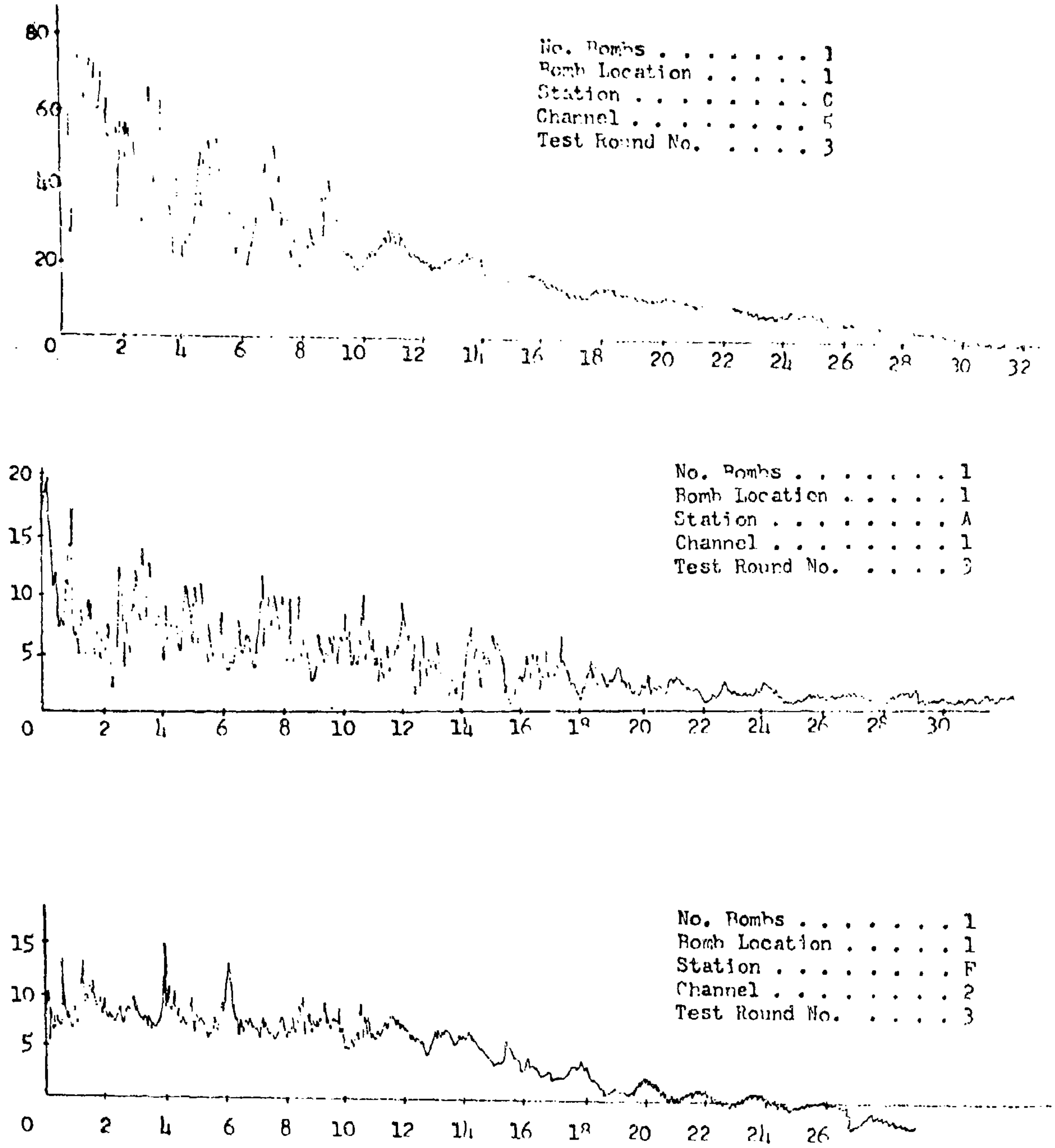

No. Bombs 1
Bomb Location 1
Station C
Channel 5
Test Round No. 3
0 20 40 60 80
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
No. Bombs 1
Bomb Location 1
Station . . . . A
Channel 1
Test Round No. 3
0 5 10 15 20
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
No. Bombs 1
Bomb Location 1
Station . . . . F
Channel 2
Test Round No. 3
0 5 10 15
0 2 4 6 8 10 12 14 16 18 20 22 24 26

FIG. 2 CONT.

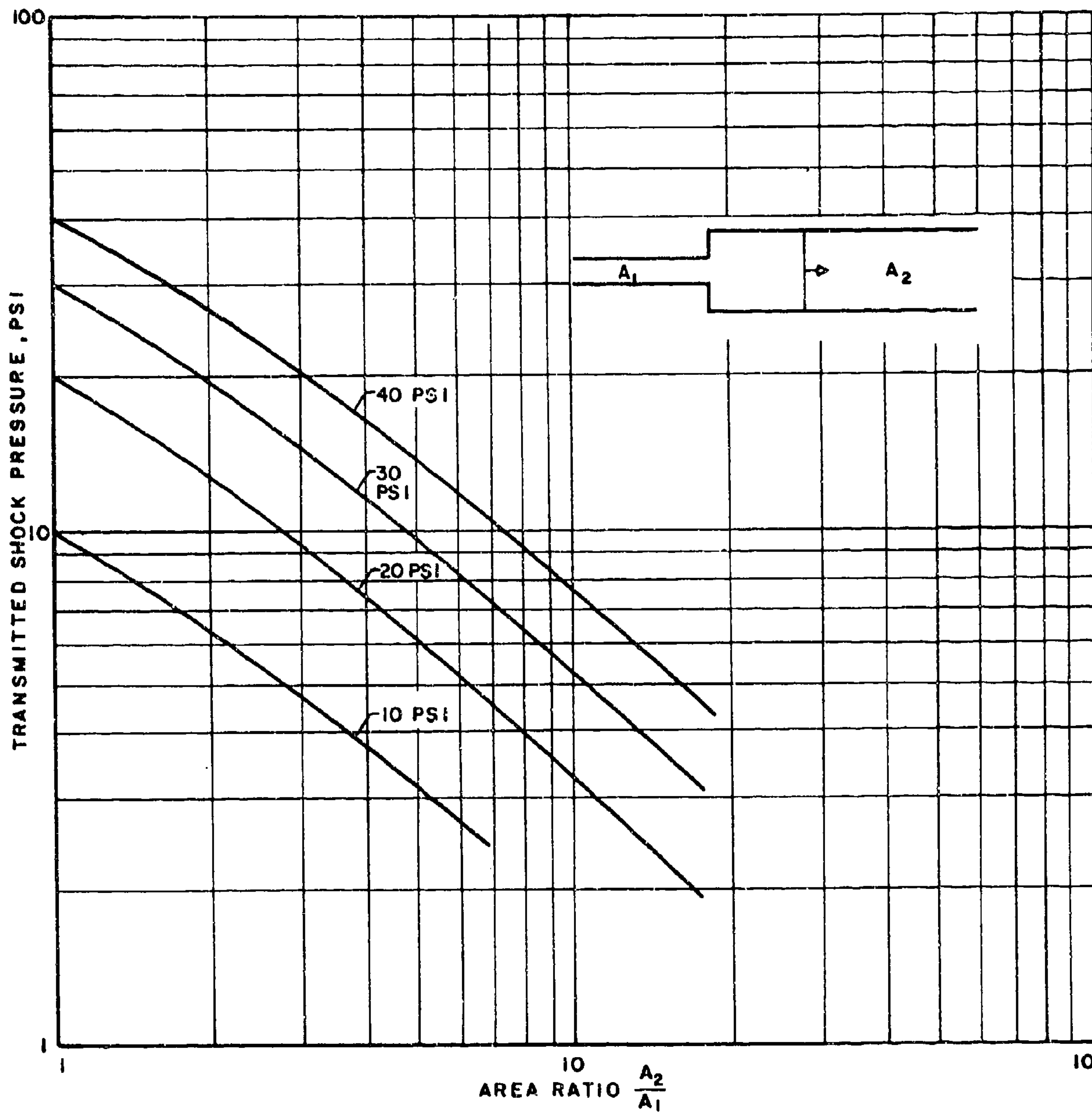


FIG. 3 SHOCK WAVE TRANSMITTED THROUGH AN AREA INCREASE IN A DUCT

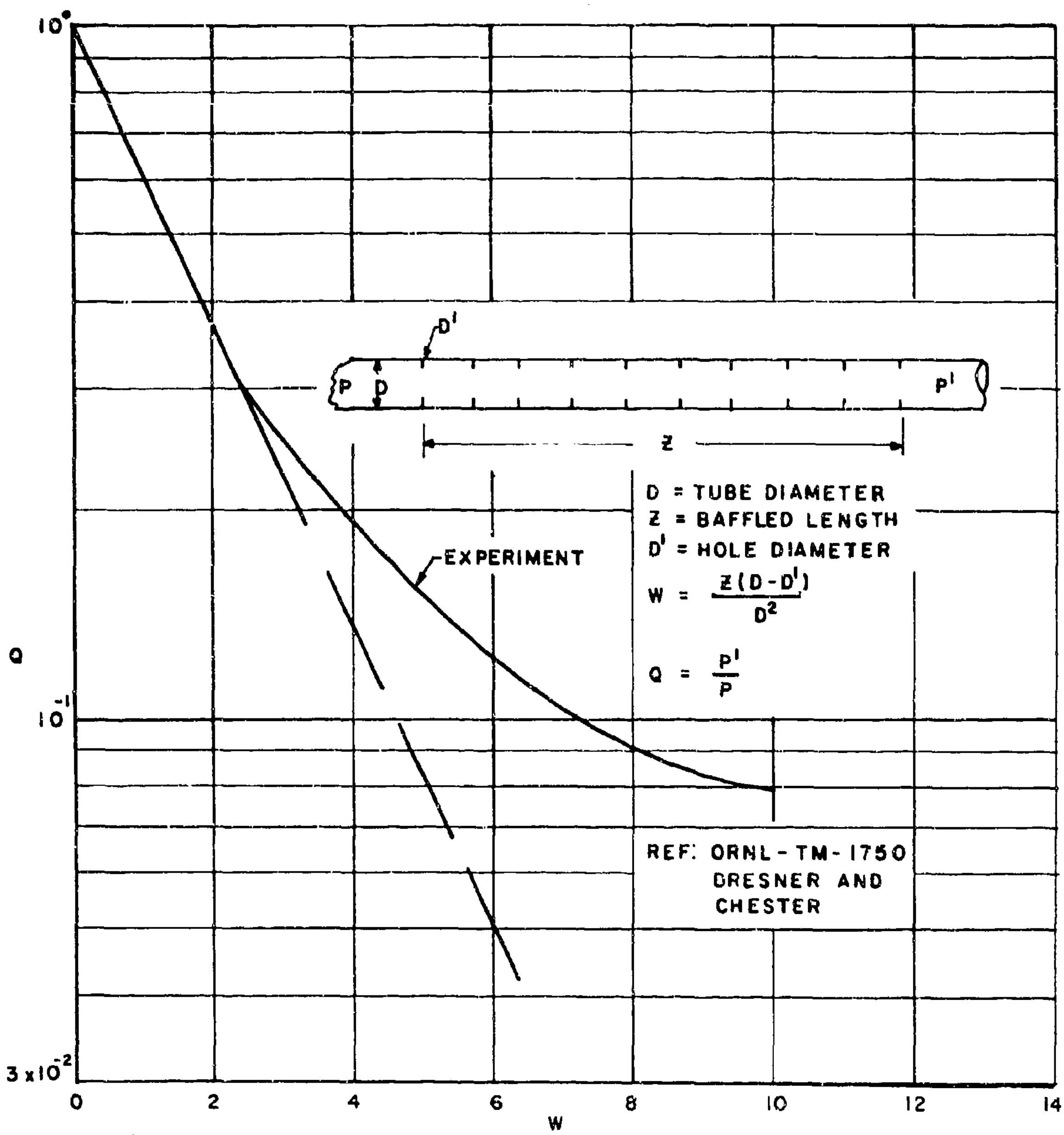


FIG. 4 ATTENUATION OF A SHOCK WAVE BY A BAFFLE

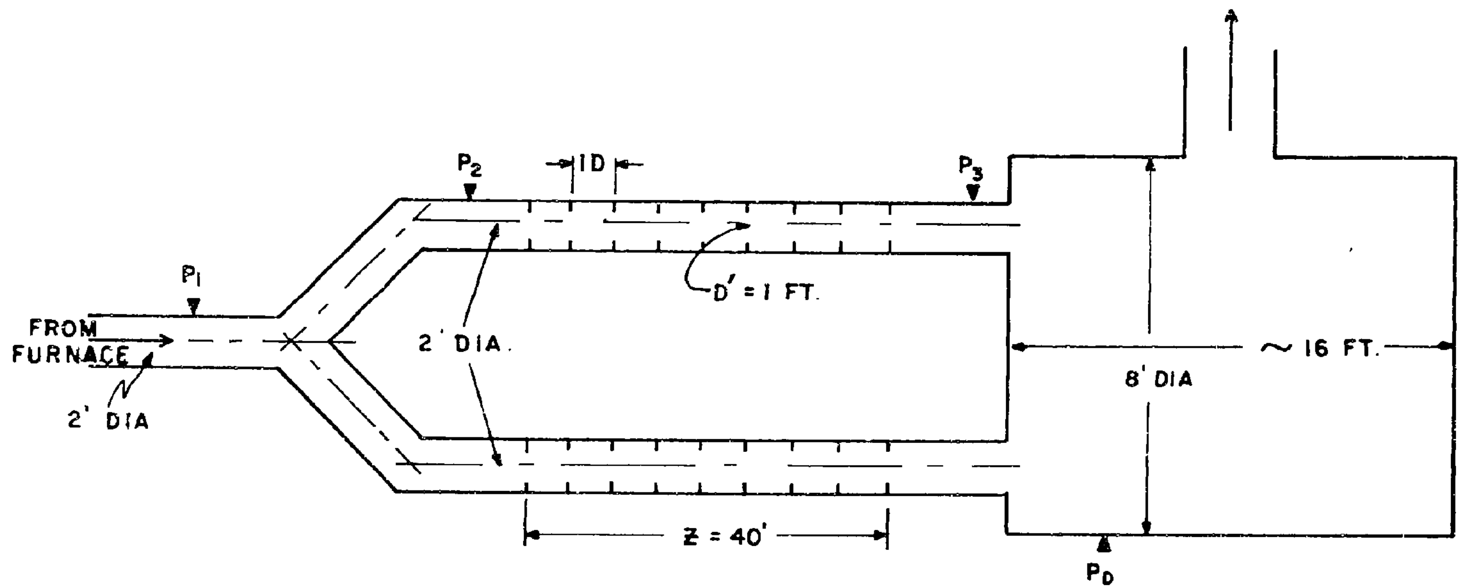


FIG. 5 ATTENUATION SCHEME

"HUMAN DYNAMICS OF ACCIDENTS"

by

ANCHARD F. ZELLER, PHD

Life Sciences Group
Directorate of Aerospace Safety
Deputy Inspector General for Inspection and Safety, HQ USAF
Norton Air Force Base, California

PRECEDING PAGE BLANK

"HUMAN DYNAMICS OF ACCIDENTS"

The history of explosives accidents is the history of human error committed by often well-selected, well-trained, well-motivated, and good-intentioned individuals who unintentionally set in motion forces which caused destruction, sometimes in awesome proportions. The question which this fact immediately brings into focus is how this can be and why such actions occur. In order to answer these, it is necessary to consider man in a total working environment and to understand the dynamic interrelations between an individual and the tools and equipment with which he works.

Any task involves an interrelation of people and equipment in an environment which is organized and controlled through a management process. When the equipment is considered, especially when this happens to be explosive in nature, it is easy to accept that there are

designed limitations which must be considered if a safe and successful operation is to be completed. It is less frequently recognized that there are limitations within the man which are equally important and that infringing upon these can result in a breakdown of the total man/equipment complex just as effectively as exceeding the limitations of the hardware can result in such a breakdown. The end result in either case may range from ineffective and wasted operation to major destruction, with concomitant death and injury.

The purpose of the present discussion is to consider some of the limitations inherent in all individuals, as well as some which are specific to unique individuals, and to show how these must be considered if efficiency is to be maintained and if accidents are to be prevented.

To attempt in the course of a single presentation to cover with any completeness the limitations of the human which are conducive to accidents is an almost impossible task. It is apparent that human beings are physical structures and that the man's physique and his sensory limitations impose limits which cannot be exceeded. Obviously, he can only see so far; he cannot see in the dark; he can only move so fast; he can only lift so much. Physiologically, it is also apparent that man, as a

biochemical being, suffers major decrease in efficiency when he is ill, tired, drugged, or is operating in an atmosphere low in oxygen or oversaturated with noxious chemicals. While each of these limitations can be expanded to benefit understanding of the problems of accident prevention, the current discussion will be further limited to exclude these, and will rather be concerned with what is, in many ways, a much less tangible, but certainly equally important, area of psychological limitations. These include man's intellectual capacities, his aptitude, learning ability, his emotional reactions, the effect of cultural patterns, and the all-consuming need for self-respect inherent in all.

LEARNING

Learning is such a commonplace occurrence that the fact that it is taking place almost continuously is often overlooked. Unlike some animals, which apparently perform complex activities without the benefit of this process, the human being must go through the often painful and tortuous process of modifying his attitudes and actions so that the desired results can be attained.

Some learning involves intentional training. Here a conscientious effort is made in a formal setting to impart specific ideas or skills to some individual. In

the training process itself there are four variables which need to be considered. There is, first, the material to be learned, then the individual to do the training; there is the system to be used for the training process and finally, the individual who must be trained.

The material to be learned varies from position to position and from industry to industry, and this changes from time to time. There must always be a conscious effort to systematize what must be known and present this to the individual in some reasonable fashion. In many instances, technicians acquainted with the developmental process, but with little knowledge of formal training, become the teachers. Without in any way degrading the competence or ingenuity of these individuals, this process often resembles the time-honored parable of the blind leading the blind. Attention must always be given to the fact that the ability to do is not necessarily the ability to teach. If efficient operation is to be maintained, carefully chosen teachers must be utilized.

The teaching system itself may vary from highly formal classroom training for some skills to informal on-the-job training, which all too often represents a catch-as-catch-can basis. Again, if efficiency, effectiveness, and accident-free operation are to be maintained, there should be a formal training system developed with

systematic instruction, a method of evaluating and a method of systematic refresher courses as technical innovations are developed. It would be gratifying to report that every individual is eager, motivated, and capable of learning any activity. Unfortunately, this is not true. It would also be gratifying to be able to report that learning was instantaneous. This is also not true. Exactly what changes take place in the nervous system when a new idea is developed or a new skill acquired is not clearly understood, but observable changes in behavior do demonstrate that some change does occur, and this change takes time. It is usually the result of repetition and continuous practice. The skilled pianist or figure skater who spends hundreds of hours perfecting minor techniques demonstrates the difficulties which some of the niceties of learning require. Although few aspects of most people's existence require this perfection, most do require more skill than the simple ability to twist two wires together or tighten a bolt by sheer force. Also, because an individual is exposed to a course in training does not mean he has learned the material.

Experience in many areas involving many people has demonstrated that learning is consistently associated with errors and that these errors decrease in a systematic fashion

with time and practice. Because of the consistency of this, the term "learning curve" has been applied to this pattern of improvement. It is readily apparent in many areas, for instance, in aircraft accidents related to the experience level of pilots. Industry utilizes this same term to describe the improvement in efficiency and reduction in cost of a new production item. With time, there is a leveling off at some point of efficiency ordinarily short of perfection.

Unfortunately, as slow and painful as learning is, the acquired knowledge is not the individual's permanent property; forgetting is a very active process. It is common to look at an individual's brochure and see that a course has been accomplished and assume implicitly that the individual knows the material presented. This is quite often a false assumption. What he does know is that which he ordinarily accomplishes on a day-to-day basis. The remainder of the material to which he has been exposed has been lost, depending on many factors, such as overall learning, basic competence, association with the present task, and general intent to remember. The point is that when a job must be accomplished, memory cannot always be trusted, even when the task is routine. Persons in supervisory positions must recognize this and provide methods for accounting for it. Another unwarranted assumption about learning is that because an individual has

learned to do a number of quite simple tasks, he can do them all concurrently. A typical problem in Air Force operation arises in the minitions loading area where a single person may be expected to load many kinds of armament. Although he has done any one a number of times and is capable of doing them all with proper time, the expectation that these activities can be successfully accomplished at random when a great variety of procedures is involved is completely unsound. The human system can be overloaded by the sheer number of even simple tasks.

This brings into focus another limitation of learning which has been explored repeatedly in the laboratory and which is as applicable to the lower animals as it is to man. It is given many names but is most commonly called "habit interference." When two activities are learned in sequence which have elements in common, the later learned replaces the older. But in an emergency or when the individual is otherwise distracted, the older habit pattern automatically reinstates itself. This in some instances can and has proved critical. Different torque values for similar components might well elicit this phenomenon. This reemphasizes the need for constant rechecks to insure that proper practices are being followed.

The aerospace industry is replete with examples of design which have directly conflicted with this human limitation. The location of the canopy ejection mechanism on a jet trainer and the proximity of the gear and flaps on some aircraft are well known correlates of accidents attributable to habit interference.

Training, although very important, is only one of many variables which contribute to effectiveness. There are many others which directly affect both an individual's learning ability and his subsequent job effectiveness. Some are the result of his own developmental process over which management has little direct control. The fact that these exist, however, should be recognized and the important role which they play given full consideration.

HABITUAL MODES OF RESPONSE

Everyone develops certain habitual modes of response. The development of these involves the interrelations of at least three variables: needs within the individual which he feels have to be satisfied; goals which if achieved will satisfy these needs; and, unfortunately, barriers which, by the nature of the living process, appear to consistently be placed between the need and the goal to be achieved. The way in which an individual handles this combination of

variables will, to a great extent, determine his general approach to living.

At the beginning it should be stated that the ideal solution to this problem is an evaluation of the need, the goal, and the barrier, an evaluation of the rules and regulations which apply to the particular problem at hand, and the systematic development of adequate solutions in keeping with the rules of the game so that the goal is legitimately achieved. Many times this cannot be done because of circumstances. The well-adjusted and mature individual recognizes this and, having evaluated the situation thoroughly and tried all the legitimate approaches, accepts that for the time being this particular goal cannot be achieved; so he unemotionally puts this aside with a reservation that if circumstances change, this problem will again be engaged. The number of mature individuals who approach living so systematically are, unfortunately, relatively few.

There are many other solutions to the need-goal-barrier combination which are developed and which can cause both the individual and society, as well as, in this particular context, a business organization, a great deal of trouble. There are, for example, those who choose to ignore the barriers which may be in the form of rules or social customs, who flagrantly disregard these, and achieve their goals in a quite direct

although often socially unapproved or even illegal fashion. These individuals who find that this is a satisfactory approach to one problem are very apt to repeat it in another context and, if repeated often enough, this is the pattern which leads to delinquency and, eventually, criminal behavior. There are many, however, who, while following this approach, manage to skirt clear of the law, but whose acceptance of rules and regulations is minimal.

Why some people develop in one way and some in another is not readily understood, but there are still other solutions which people find to the need-goal-barrier combination. There are those, for example, who, when meeting a barrier, find it difficult to mobilize their resources to attack the problem legitimately. They, rather, see only the barrier instead of the goal, and the fear of failure is so great that they would prefer to give up the goal than accept the feeling of defeat which would come from not achieving it. Because, however, the need still exists, some solution must be developed. If a real victory cannot be won, a fantasied one, although much less satisfying, still serves to fill some of the psychic needs involved. The problem with this solution is that, as in all processes, accomplishment follows the learning curve, so that once success is achieved, it is easier the next time. The individual who has not achieved success but who has

retreated into fantasy as a solution is very likely to adopt this same approach when other problems involving goals and barriers arise. With time, these individuals become withdrawn, seclusive, often secretive, fearful of failure, yet with intense needs which are only partially satisfied through fantasied achievement.

Still another solution to the goal-barrier problem is exemplified by the individual who, having perceived the problem and deciding that it is too difficult for him to solve, from that point on ignores it. There is no retreat into fantasy; there is nc overriding of the rules; the problem is simply not engaged at all. Because there are many problems in life which can at least temporarily be treated in this fashion, this individual too has learned an approach to life which, as it was temporarily successful, will be repeated. The problem with this is that reality has a way of forcing itself to attention. Problems cannot be permanently ignored. Because the basic needs were not fulfilled, these eventually reassert themselves. While the individual in the first place had only one problem to face, at the time he is forced to reexamine the situation he may have accumulated literally dozens. The stark, overwhelming nature of this mass of barriers to be attacked at the same time is so overpowering that he can only wring his hands, figuratively speaking, and

react with depression and gloom. This, however, is a very unfortunate psychic condition in which to remain, so he attacks this problem, as he has attacked all others, with the only solution he has readily at hand; namely, to ignore the whole mess. Soon he has managed to what is technically called repress all of his problems and is now a happy, even elated, individual. Because the problems were not solved, however, they reassert themselves and there is a constant repetition of this temperamental shift from depression and despair to happiness and optimism.

It would not be possible to list all of the kinds of approaches which are developed. There is another group, however, which is of interest. These are the individuals who attempt to go around the barrier and achieve their goals. These people do not override it nor do they retreat, but they develop various subterfuges to get what they want while still maintaining the pretense of active accomplishment. Take, for example, the individual who is faced with two need-goal-barrier problems at the same time. It is only natural that he will choose the easier of the two, and from this success comes an enlightening revelation to him; namely, that whenever a problem appears, if he can find another which he can accomplish at the same time and be busy doing this, he has a completely legitimate reason for not having done the harder of the two.

As life progresses, it becomes more and more difficult to always have on tap a second type of activity to substitute. The result is that some people develop very bizarre behavior in the face of a problem simply because they have reverted back to some behavior which at one time was very meaningful, but which in the present context appears to be and is totally unrelated to the current situation. Another group of individuals who adopt much this same solution are those who find that alcohol or dope addiction or excessive sexual activities all serve the same purpose. Because these all involve strong emotional overtones, it is easy to ignore the real problems which should be being engaged while this substitute activity is under way.

Another group of persons who attempt to get around the barriers and still achieve their goals are those who find that at the time some problem arises they are physically incapacitated. Now no one really expects a sick person to function very efficiently. The result is that this individual too has had a great revelation; namely, that the pressures of life can be greatly reduced when he is ill. Depending upon temperamental variables which it is difficult to predict, some individuals will become incapacitated by blatantly stating that they have pains or cramps, or that they can't see, without any real attempt to correlate their illnesses with legitimate

disease processes. Others with much greater social consciousness will attempt to develop miseries which correlate nicely to well-known pathologies. The end result is the same: an individual is attempting to achieve the goal without having to attack the barrier and is using his illness to obtain both psychic reward through sympathy and the end result which is desired at the moment.

One other group of individuals which differs somewhat from the foregoing consists of those who, having tried and failed, look for a reason and find one in the fact that someone else basically was responsible for their failure. This, carried to the extreme, results in a pattern of behavior characterized by suspicion, distrust, and a general feeling of being the center of opposition from others.

PSYCHOSOCIAL FACTORS

An individual has many other characteristics which tend to make him unique. Not only his basic aptitudes, intelligence, degree of training, and habitual modes of reaction as discussed, but also such things as his temperament type and social-cultural-ethnic background tend to make each individual completely unique.

The need to conform and be accepted by the group is an integral and intense force in almost every human being. Even though individuals develop their own unique responses

within a culture, it has long been recognized that attitudes and modes of expression are, to a great extent, a reflection of a culture. Fads and fashions, acceptance of social mores and institutions, and the partial sublimation of one's own desires for a socially approved greater gain all stem from the desire for social approval and acceptance. It is in the young, who are not yet secure in the acceptance of their own place in society, that this need for social approval is most obvious. The approval sought is not necessarily that of elders or superiors, however, but that of the group with which the individual identifies. Although younger individuals may reject some of the patterns of the older, they are nevertheless directly influenced by them. In this regard, it is pertinent to point out that the process of attempting to teach one set of values while manifesting another is almost sure to result in social conflict.

One of the social patterns which younger individuals are faced with accepting or rejecting is the use of alcohol. Americans, having once asserted their right to drink alcoholic beverages, appear particularly loath to accept the fact that alcohol can be the source of much difficulty. Although there is almost universal lip service given to the fact that alcohol and skilled behavior should not mix, emotional acceptance of this fact, especially when small

quantities of alcohol are involved, is much more difficult. While the problem is best documented in the driving area, alcohol is detrimental to any skilled activity. The manager striving for high efficiency and good quality control will find almost nothing as detrimental to these ends as a work force under the influence of alcohol. The same applies to the aftermath or refractory phase while the individual is recuperating, commonly called a hangover.

While the younger generation has not rejected the alcohol in the "alcoholic culture," they have added to it a variety of other drugs. The specific effects of these are not important in this context. The fact that it is a social custom, that it is highly accepted, and that the drug culture is the "in" culture is of great importance for those seriously concerned with understanding the dynamics of behavior and human limitations which can precipitate accidents.

Whether considering the cultural patterns or the individual responses which an individual adopts, it should be recognized that as bizarre as some behavior may seem to an outsider, to the individual involved it is meaningful and pertinent. For him it serves a purpose in that it achieves some goal which to him is important. This need for self-fulfillment is inherent in all individuals. The wise manager is one who understands these needs and who utilizes them to achieve his own ends.

Every individual must be assured basic survival. This implies some form of adequate compensation. He must, however, also receive psychic pay, which results in a feeling of self-wor . It is this form of compensation which is so often neglected. If the mores of a work group can be oriented toward pride in production, safe behavior, and all of the other behaviors which are accepted as virtues by those attempting to run a good program, then the individuals within the program find it easy to conform to the behavior. If, however, the group is oriented toward disobedience, slow-downs, minimum production and maximum risk-taking, and is, in general, antagonistic to the higher echelons of the structure of which it is a part, then no amount of programming can achieve the desired end objectives.

In all groups there are leaders of many kinds, both those assigned and those self-chosen. The wise manager, recognizing the impact which the leaders, particularly the self-chosen ones, have on overall behavior, will take considerable effort to identify these, and will enlist their assistance in developing a good, waste-free, and safe program.

THE CURRENT SETTING

While theory is of some interest, it is always good to put the theory into the context of a real-life setting. It is suggested that the explosives industry, like the military

forces and the aerospace industry, is currently facing a particularly acute problem because of social forces taking place outside the industry itself. Whether one looks upon the changes taking place in our culture as a revolution or whether one is more inclined to believe that only routine evolutionary processes are at work, the fact remains that there are modifications under way which have major impacts. First, any restriction of programs requires movement of men; it requires change of assignment and change of management responsibilities. The result is that well-developed, smoothly operating procedures are in a constant state of modification--even disruption. People who have grown proficient in a task find themselves with either increased or changed responsibilities. The resultant management disruption is almost certain to result in relaxation, which in turn is conducive to error and consequent accidents. Not only, however, is

the system affected, but individuals are also affected. New and increased responsibility not only requires additional effort, but is conducive to anxiety and tension, regardless of the setting. In the current atmosphere, this anxiety and tension are accentuated by the attitude toward the overall task being accomplished. Many veterans of Southeast Asia found their assignments there distasteful but rewarding in that they represented a response to a need which had to be fulfilled. This need was recognized by their contemporaries and regardless of how difficult, there was a feeling of accomplishment and satisfaction in a job well done. With the general shift in the public attitude, members of the armed forces find that they not only are no longer looked upon favorably, but that this association has resulted in social rejection by major segments of the population at large. Because they themselves are representative of this population from which they are drawn, the conflict in values becomes particularly acute.

While it is perhaps easier to isolate the dynamic effects of these changes on members of the armed forces, the same changes are taking place in the civilian community as well. Those who feel the impact most immediately are those in the allied aerospace industries. The shift in public sentiment and the change in mission have resulted

in the need for major modifications within this industrial segment. Long-time employees find themselves faced with the necessity for changing plans, in some instances changing vocational goals and areas.

It is suggested that the explosives field is in the same flux and that the detrimental effects will be no less prevalent in this area than in the others. At one extreme, a worker can view himself as a true patriot, producing equipment for the protection of his country, or at the other, can become dejected over the widespread belief that his products are used to destroy without reason. It is almost inevitable, in the light of public sentiment, that many workers in the production of explosive ordnance have shifted their attitudes somewhat toward the latter position. In rare instances this shift of attitude, either by individuals within or outside the industry, has reached such extremes that attempts to solve the problem of destruction by destruction have been attempted. While few reach the stage of mental illness which resorts to such ends, many express their displeasure by public demonstrations and by private censures of the individuals involved in the industry.

Regardless of the idealistic values involved, the specter of unemployment also hangs over an industry whose basic commodity is in less demand. Such unemployment will

most certainly result in the same pattern described for a phasedown in military activity. Management is disrupted, workers' routines are disrupted, and new people are assigned to new tasks. Added to these skill-compromising factors are the same emotional considerations which the military man faces: fear of unemployment and anxiety concerning the future.

It is inevitable that whether an individual is within the military services or within the civilian industrial complex, anxiety-producing factors have an effect. Although these effects are somewhat unique from individual to individual, there are some reactions in common. It is easy to take short cuts, to condone practices which once would have been considered unacceptable, and to [illegible] raising issues which would call any attention to one's self and to a general deterioration of personal efficiency and self-control. That misery loves company is a truism that, like most, is not completely true; some seek solitude. It is common, however, for individuals to band together to seek solutions to their problems. In the current culture, this banding together can all too often result in greater consumption of alcohol or greater utilization of drugs, depending upon the age group and orientation of the individuals involved. These activities, while somewhat conducive to forgetting,

are not conducive to effectiveness and efficiency, and are highly conducive to errors which result in accidents.

CONCLUSION

The picture drawn is not intended to suggest that a deterioration of effectiveness and an increase in accidents is inevitable. It is intended to point out that the potential always present is considerably enhanced by circumstances of the moment, and that the wise commander or manager will recognize this potential and take steps to alleviate it. First, and most difficult, the manager must recognize that he himself is subject to the same forces and, in recognizing this, accept his need for reconsideration of his own attitudes and procedures. Next, he must recognize that while the challenge has become greater, a program based on sound management principles can survive not only successfully but even optimally under very adverse conditions. Such survival, however, is dependent upon recognizing that individuals have needs: needs for basic survival, but also needs for much more intangible but equally important psychic survival.

There are times when negative reinforcement in the form of punishment and censure are required. More frequently, positive recognition is far more effective in

enlisting the support of fellow workers, whether superiors, peers, or subordinates. Frank and open discussion of problems is always a long step in the direction of their solution.

The basic thesis of this presentation is that there are within every individual many psychological limitations and strengths of which the manager of any program must be aware if he is to achieve success, and success must be more than pure production; it must encompass production in consonance with the preservation of human dignity and human life. If waste is prevalent and/or if accidents and injury are a by-product of the program, then serious consideration must be given to some critical reevaluation. People, as individuals, have needs; if management is to achieve its goals, it must recognize this and supply the individual's needs while achieving its own. When these can be made synonymous, as in the development of accident-free procedures, the task, although large, is not insurmountable. Accidents, with their concomitant waste and loss of life, can be prevented. Recognition of man's psychological limitations is one of the major steps toward this goal.

THERMAL PROTECTION DEVELOPMENT FOR EXPLOSIVES

LCDR J. N. Kindig, Naval Air Systems Command
Session Chairman

INTRODUCTION

The agenda for this session contains presentations on the three major areas of the Navy's cook-off program. In introducing this session, I feel it is only appropriate to expound briefly on the reason for the cook-off program.

In July 1967 while on station in the Gulf of Tokin the USS FORRESTAL was conducting normal flight operations when an inadvertent rocket firing started a conflagration that cost over 100 lives. Many millions of dollars in material damage, and the operation loss of the carrier for an extended period.

In January 1969, a similar fire broke out on the USS ENTERPRISE while undergoing an Operational Readiness Inspection. Again there were numerous deaths, and catastrophic damage.

The results of the FORRESTAL investigation indicated an urgent need for standardized weapon fast cook-off information and for thermal protection for explosive ordnance. The ENTERPRISE conflagration further emphasized this need.

The nature of cook-off, the ongoing test program, the thermal protection developments in progress, and new concepts that may be incorporated in future weapon designs are the subject of this session.

What is cook-off? When a confined explosive is exposed to a significant amount of heat, the violent reaction that occurs is known as "cook-off". As a weapon is heated the explosive's rate of chemical reaction will increase to the point where the reaction is self generating and the volume of gas produced by the reaction opens the case. This case opening may vary from simple rupture to fragmentation in accordance with designed performance. The factors of concern here are the time and violence of this reaction, of prime interest, in ongoing naval efforts is the identification of fast cook-off hazards and developing the means to extend cook-off times, and, to reduce the severity of the resulting reaction.

Practical and Standardized definitions of reactions have been promulgated in NAVORD OP5, Volume 1. These describe reactions in terms of explosive reacting, blast, fragmentation, and environmental effects.

A "detonation" has occurred when the munition performs in its design mode. The maximum possible air shock is formed and essentially all of the case is broken into small fragments.

In a "partial detonation" only part of total explosive load in the munition detonates. A strong air shock and small as well as large case fragments are produced. The amount of damage and extent of case breakup into small fragments increases with the increasing amount of explosive that detonates.

In an "explosion", violent pressure rupture and fragmentation of the munition case with resulting air shock occurs. Most of metal case breaks into large pieces which are thrown about with unreacted or burning explosive.

In a "deflagration", the explosive in the munition burns. The case may rupture or the endplates blow out, however, there is no fragmentation of the case. In the case of a large rigidly confined munition, such as a G.P. Bomb, simple case rupture can be quite violent.

These standardized definitions for describing cook-off reactions have assisted in clarifying much of the ambiguity related to cook-off testing.

Serious fire-caused incidents are not limited to occurrences aboard carriers. There have been cases of extensive material damage and loss of human life due to weapon cook-off ashore in Southeast Asia. There is a continual threat of accidents involving aircraft and vehicles carrying explosives. Each of these accidents can result in weapon cook-off.

THERMAL STABILITY STUDIES ON G. P. BOMBS THERMAL PROTECTION

by

Jack M. Pakulak, Jr.

Propulsion Development Department
Naval Weapons Center
China Lake, California 93555

Introduction

The purpose of this study is to identify means by which the severity of the cook-off reaction can be reduced and the cook-off time can be extended for particular Naval weapons.

In order to accomplish this purpose, the study was divided into two parts. The first part considered the immediate problem with G. P. bombs in a fire and the second part considered the long range studies for the bombs, warheads, etc., both problems were studied concurrently. The techniques, ideas and results of these studies are given in this report, with references on specific work given from other reports.

Improved Cook-Off Time for G. P. Bombs Program

This program was managed by NMC, Pt. Mugu. The part covered here is on the thermal stability of the coating, liner and sealer materials and their possible effect on the explosive they would be in contact with. Thermal stability can be defined as the ability of a material to remain unchanged, either physically or chemically, over a period of time and when exposed to a rigorous environment. The period of time was something greater than five minutes, with hopes of ten minutes in a fire exposure, and the change would be a deflagration, instead of a detonation, for the reaction at the end of the cook-off time. The fire was the test medium by which the study was made. The time was increased by using a candidate liner material which was different from the present hot melt, and a coating on the outside of the bomb to protect the explosive from the heat of the fire. The wax sealer in the aft end of the bomb offered almost no protection against the fire, therefore a new sealer had to be used to assure at least five minutes to reaction. The type of reaction was changed by using H-6 explosive instead of Composition B explosive for the fill. Composition B explosive in a G. P. bomb will generally detonate in a fire, whereas H-6 explosive will not. In general, the longer the heat build-up in G. P. bombs caused by a low fire output or insulation, the more severe is the reaction on cook-off. In a time frame of 10-20 minutes, a H-6 loaded Mk 82 bomb can also detonate on cook-off.

In compatibility of liner materials with explosives, tests were performed in addition to the standard compatibility tests, such as VTS, DTA, color change, etc. These additional tests are covered below in the study on the effects of the liner and sealer material on the explosive.

A. Effect on thermal decomposition rate of explosive (ref. 1).

$$TNT \xrightarrow{k_1} \text{products}$$

$$TNT + \text{liner/sealer} \xrightarrow{k_2} \text{products}$$

where: $k_2 > k_1$ by some factor

B. Effects on chemical stability of the explosive (ref. 2).

$Al(H\text{-}6) + H_2O$ (liner product) $\longrightarrow H_2 + Al(OH)_3$

TNT + liner $\longrightarrow$ Additions products with TNT

TNT + sealer $\longrightarrow$ TNT-sealer solution-addition products

C. Reactions of TNT with acids and bases (ref. 3).

TNT + acid $\longrightarrow$ almost no reaction, except for very strong acids (i.e. concentrated nitric acid) and at elevated temperatures.

TNT + base $\longrightarrow$ Meisenheimer's reaction. An alkaline material with TNT can effect a considerable change in the TNT, yielding red, brown, purple, etc., colored addition products. These are usually much more sensitive to mechanical and thermal shock than TNT.

Fig. 1 outlines, for example, the effect of liner and sealer materials on the thermal decomposition of TNT explosive (ref. 1). The data is presented as half-life, that is, the amount of time for half of the TNT to disappear. This time is reduced in all cases. In some, the amount of time reduced is small and others the reduction is 100 fold. As the data stands in this plot, it is an indication of possible problems with a liner or sealer and the explosive. Several liner materials have less an effect than does the standard hot melt. The kinetic data from this decomposition study can be used in heat flow equations to predict the critical temperature. The critical temperature is the heat balance between heat generated in the explosive-liner and the heat transferred to its environment. Some selected values are shown below:

Critical and Surface Temperature Calculations
(δ = 91.5 and δ = 2 for 8 minute to cook-off)

Material	TNT/asphalt	TNT/sealer	TNT/liner (1)	TNT/liner (2)	TNT
activation energy (kcal/mole)	32.0	33.8	33.3	30.5	30.1
T_m (°C)(δ = 91.5)	142	133	171	149	
T_m (°C)(δ = 2)	105	98	130	107	130
T_1 (°C)(δ = 2)	214	195	249	225	267

The shape factor, δ, of 91.5 (adiabatic condition) would be for a 0.5-inch reaction zone of TNT/material for an estimated ten-inch diameter bomb or warhead, for the mass and geometry consideration. For a shape factor of 2, a solid cylinder would be the case. The time to cook-off is constant and it is based on a shape factor of 2, steady state conditions, and a zero-reaction model. Therefore, once pass the protective liner or sealer thermal protection, the TNT would thermally decompose fastest with the sealer, then the asphalt liner, Liner #2, Liner #1, and last the TNT with no liner interaction.

Liner #1 was selected for further study. Since the materials were of a proprietory type, their composition was unknown. Liner #1 yielded the following data.

Liner #1 $\xrightarrow{\Delta}$ water + product #1,

which would on contact with an explosive:

water + Al (H-6 explosive) $\longrightarrow$ H_2 + products

product #1 + TNT $\longrightarrow$ red complex of lower thermal stability

Liner #1 $\xrightarrow{\text{cooling}}$ freeze (water)-crack up

When Liner #1 was cast on a steel plate or in a bomb case, it suffered several problems; they were:

1. Liner #1 would not stay bonded to the steel.
2. Because of the water continuously coming off, rust would form at the steel/liner interface.
3. When the steel plate, with Liner #1 on the back side, was heated in a flame, Liner #1 would first soften, then the water would separate and bubble up from the hot metal surface like a "mud pot". This would melt the TNT present and the melted TNT would flow down the "mud pot" hole toward the steel surface. The TNT apparently reacted and came back up the hole as a deep red color material. This was a possible hypothesis for the short cook-off times for the bombs containing this liner.

4. Quality control could be a problem. The thickness varied from a quarter of an inch to more than an inch in a section from a single bomb. The amount of water in Liner #1 varied from sample to sample in a given lot or bomb; the vendor admitted that it was a problem.

Liner #2, and the other liner materials, offered similar problems as Liner #1, therefore, as of now, the use of the hot melt liner was retained (ref. 2).

The sealer material tested had no competition except the wax normally used. This wax was placed on the explosive before a crust was formed. Then before the explosive and wax solidized, the bombs were laid on their side to form a void in a selected portion of the bomb. The wax thickness is about 1/16 of an inch on the back steel plate of the bomb, because the melted wax would "float-up" and move away from this back plate. The candidate sealer was an asphaltic filled polyurethane material. The material has reasonable thermal properties. It started to decompose at about 150°C and would burn. It did have problems and these were:

1. Accelerated the thermal decomposition of TNT faster than any other material tested. It also accelerated the thermal decomposition of Composition B.
2. Rapidly dissolved the TNT. The sealer was made from a two-part system and the part containing the isocyanate monomer would dissolve the TNT. In an aged H-6 loaded bomb (WR-50 safety test) where this sealer was used, the TNT was found throughout the sealer. On microscopic examination, red crystals were found throughout the sealer material. White salt-like crystals were also found in a boundary layer between the explosive and the sealer. The white salt-like crystals were RDX. Little or no TNT was found in the boundary layer. In non-aged bombs, the presence of TNT in the sealer was less pronounced. In three bombs, TNT could be found only ¼-½-inch into the sealer material. It appeared that the TNT migrated more on accelerated aging rather than when first loaded. IR and DSC were the methods of analysis.
3. After the TNT was dissolved into the sealer, it reacted with one of the components to form a reddish-pink complex. This complex was purified; it had a lower thermal stability than the TNT alone.

In order to get longer cook-off times, this sealer material has been used. A layer of a non-soluble wax between the explosive and sealer would help solve most of the above problems.

In summary, the above study shows us what we have to live with and that it should not be treated as a yes or no compatibility problem. A decision in this case should be based on what you want to live with for thermal stability, chemical reactivity, and aging problems versus what is gained in time to cook-off for a bomb in a fire. This leaves the door open for new products to give even better protection or less possible chemical, thermal and aging stability problems.

Advanced Cook-Off Studies

The objective of this program is to study and to identify means by which the severity of the cook-off reaction can be reduced and the cook-off time can be extended for the particular Naval weapons.

In order to accomplish these objectives, two approaches are being considered for bombs and warheads. The first is the outgassing study where the bomb or warhead is ruptured prior to cook-off and the explosive is allowed to burn in an unconfined condition. The second approach is to study methods to inhibit the transition from deflagration to detonation during thermal initiation. Both approaches could reduce the severity of the cook-off reaction and also could be utilized to extend the cook-off time. For rocket or missile motors, the objective will be to extend the cook-off time by studying the thermal stability of the propellant being used and of any type of thermal insulator or intumescent material under consideration. Consideration will be made for slowing down the burning rate of a propellant by adding selected chemical additives to the liner material, as in the case with explosives.

Outgassing Study Approach

The initial part of this study was to incorporate an outgassing chemical with the hot-melt or cavity paint liner used in warheads and bombs. The idea is that the outgassing chemical in the liner will decompose into a gas with sufficient pressure to rupture the warhead or bomb case when the warhead or bomb is subjected to an external heat source such as an enveloping flame. This would allow the explosive material to burn in an unconfined condition. The outgassing chemical used in the liner should have certain properties. These are listed below:

1. An endothermic decomposition reaction is preferred to an exothermic decomposition.
2. The chemical should have a high density and decompose completely into a gas.
3. The gas generated should have a low molecular weight.
4. The chemical should not start to decompose until a desired temperature is reached and then it should release the gas quickly.
5. The mole ratio of gas generated to chemical used should be high. The required ratio depends on the pressure requirement.
6. The chemical should be compatible with the explosive to be used.
7. The chemical should be readily available and at low cost.

The next part is to combine a selected outgassing chemical with a liner material which has sufficient structural strength to support the explosive load in a warhead or bomb during a fast cook-off test. The reason for this type of liner material is that many of the liners now in use will melt and allow the explosive to come in contact with the hot wall of the warhead or bomb.

Several outgassing chemicals are under consideration but only ammonium oxalate has been used in the laboratory and in small and full-scale field testing.

Inhibition of Violent Cook-Off Reaction Study

This study is concerned with methods that will inhibit the deflagration to detonation and transition (DDT) during thermal initiation for a given explosive under known confinement. Two methods are considered in this study to solve the problem. The first method is a metal additive to the explosive. The second method is a chemical additive that affects the decomposition rate of a given explosive under confined conditions.

The use of metal additives in explosives is not new, but the study of metal additives in an explosive to inhibit DDT should be new. The presence of aluminum powder in an explosive in certain explosive formulations apparently reduces the possibility of a detonation. Such is the example of Composition B and H-6 explosives, where H-6 is Composition B with 20% aluminum powder. G. P. bombs loaded with H-6, up to the MK 82 size, usually only deflagrated (like a pressure rupture) and burned whereas Composition B loaded bombs usually detonated, when both were subjected to the enveloping flame of a fast cook-off test (WR-50 Safety Test, Ref. (4)). When an insulating coating has been applied to the exterior

of the H-6 loaded MK 82, and under similar test conditions, the reaction has been more violent, where explosions, partial detonations or detonations have resulted in some fast cook-off tests as defined in ref (5). The reaction appeared to be more violent with the longer reaction times. Another comparison would be TNT and Tritonal but data is scattered and incomplete. The presence of aluminum powder is not always desirable in a explosive formulation, especially for shape charges, unless the percent of aluminum can be kept to a minimum (estimated at 4%).

The other part of this study was the addition of a chemical to the liner material or to the explosive itself that would slow down or inhibit DDT on thermal initiation. Glazkova (ref 6) has indicated that a mild reducing agent would react or absorb the nitro groups as the explosive decomposes. This would act as a burning rate modifier for explosives. From this study by Glazkova, two of the suggested additives are urethane and ammonium oxalate. The polyurethane is used in two Navy explosives and with aluminum in one formulation. The aluminum formulation contains two ingredients that should inhibit the DDT during thermal initiation.

Experimental Studies

Ammonium oxalate (AO) has been used as an outgassing and inhibiting chemical in several studies. The studies included thermal decomposition of AO, alone and with explosives, small-scale studies (approximately two pounds) and full-scale studies with MK 82 bombs and Condor warheads (ref 7). The apparent decomposition mechanism of AO indicates that it goes to ammonia plus oxalic acid, which in turn decomposes into formic acid and carbon dioxide. Formic acid is a strong reducing agent which apparently can affect the decomposition of the explosive. The formic acid decomposes into carbon monoxide and water. If AO can become a strong reducing agent on heating, then AO would be nearly ideal as a chemical additive to a liner system in a bomb or warhead. The use of AO in a explosive formulation is possible and should control the decomposition rate on heating. The use of AO in small-scale studies, of about two pounds of explosives per test, showed marked decrease in the violent reaction and extended the time to cook off. The heating rate used in these tests was similar to that for a G. P. bomb in a fire. In a series of fast cook off tests with the Condor warhead with Composition B explosive, the use of AO in the liner (0.1 inch) reduced the reaction from a detonation to a mild deflagration or burning and increased the time to cook-off from about 2.5 minutes to about 5 minutes. In the tests with the MK 82 bombs, AO in the liner (0.1 inch)

could not be tested completely because no sealer for the aft end of the bomb was available at the time. The test results were one detonation, one explosion (large frags), and one deflagration. All bombs were loaded with Composition B explosive.

Many other chemicals are under study that may function in a dual manner. The burning rate of explosives are sensitive to pressure, and above a given pressure for a specific explosive, the burning rate rises rapidly with pressure. From this, the need exists for a pressure term in general heat flow equations used in predicting critical temperature and time to cook off. This information is needed in order to determine if a bomb or warhead case can be ruptured while the explosive is burning, without a detonation taking place.

References

1. Naval Weapons Center. Thermal Decomposition of Explosives. Part 8. The Reactions of Composition B and TNT in the Presence of Various Potential Cavity Liners and Sealants (U), by Taylor B. Joyner. China Lake, Calif., NWC, 1971. (NWC TP 4709, Part 8, publication CONFIDENTIAL).
2. -------. Thermal Analysis Studies on Candidate Liners, Coatings, and a Sealer Material for Thermally Protected MK 80 Series Bombs (U), by Jack M. Pakulak, Jr., and Edward Kuletz. China Lake, Calif., NWC, 1971. (NWC TP 5146, in process, publication UNCLASSIFIED).
3. Urbanski, T. Chemistry and Technology of Explosives. Vol. 1. New York, Pergamon Press, 1964. Pp 290-311.
4. Bureau of Naval Weapons, Navy Department. Naval Weapons Requirements. Warhead Safety Tests, Minimum for Air, Surface and Underwater Launched Weapons (Excluding Mine and Nuclear Warheads). (WR-50, dated 13 February 1964, publication UNCLASSIFIED).
5. Naval Ordnance Systems Command, Navy Department. Standard Terminology for Ordnance Explosive Reactions Obtained by Cook-Off. (NAVORDNOTE 8020, ORD-93221, 23 April 1969, publication UNCLASSIFIED).
6. Glaskova, A. P. "On Deceleration of Chemical Reactions in Deflagration." Combustion and Flame, Vol. 13, No. 1 (Feb. 1969), p55.
7. Naval Weapons Center. Techniques for Use in Weapons to Reduce Hazards of Cook-Off. Part 1. Outgassing and Inhibiting Chemicals for Warhead Case Rupture (U), by Jack M. Pakulak, Jr. China Lake, Calif., NWC, 1971. (NWC TP 5243, Part 1, in process, UNCLASSIFIED).

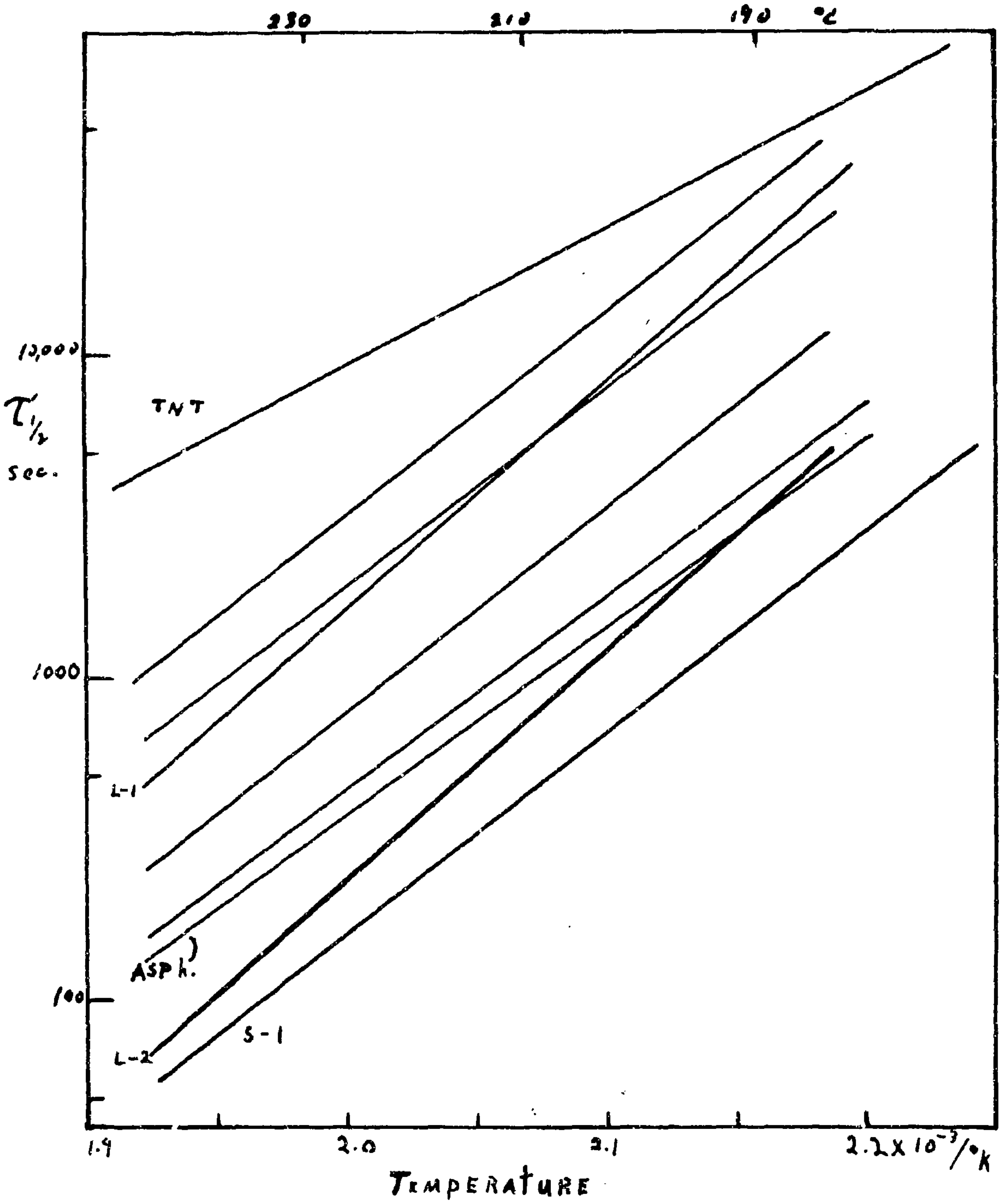


Fig. 1. Effect of liners and sealer material on the thermal decomposition of TNT.

WEAPONS SURVIVABILITY IN FIRE
by

C. P. Hontgas, NWL, Dahlgren, Virginia

HISTORY

The FORRESTAL and ENTERPRISE conflagration have exposed a deficiency in the knowledge of hazards associated with flame envelopment of air launched weapons. In order to determine these hazards so that effective means of minimizing or eliminating them can be developed, the Naval Weapons Laboratory, Dahlgren, was assigned by the Naval Air Systems Command the task of conducting simulated carrier flight deck fire tests. The immediate objectives were to determine fast cook-off characteristics of all ordnance that might be exposed in a flight deck fire environment and to provide data for safety of fire fighting personnel when fighting such fires. The long term objective was to provide data and investigate means of improving ordnance resistance to fast cook-off.

TEST CONFIGURATION AND PROCEDURES

Aircraft carrier fires were simulated by constructing a test pan or pit to contain an adequate amount of aircraft jet fuel that when lit, will create an engulfing flame environment. To construct a test pan the ground area to be used was cleared and leveled. In the center of the clearing an earthen retaining wall approximately 1 foot high and 1 foot thick surrounding a 20 to 35 foot square leveled area was constructed. This retaining wall constituted the outer bounds of the test pan. The pan was then lined with polyethylene to retain a few inches of water that provides a level surface on which to float the JP-4 or JP-5 jet fuel used as the energy source for all

fires. The ordnance under test was horizontally positioned in the center of the pan at the fuel level or up to a height of 3.5 feet. This height is dependent on the simulation of the ordnance position when racked to an aircraft. Thirty gallons of automotive gasoline was poured over the jet fuel to insure rapid spreading of the fire over the entire surface. A constant check of wind velocity was made and in the event winds exceeded 2 knots for a small pan (20 to 28 feet square) or 4 knots for a larger pan (29 to 35 feet square), the test was postopned. To eliminate postponement of tests in high winds (up to 20 knots) the test pit was constructed. The pit consists of a hole approximately 5 feet deep of the same outside dimensions as the pan. Three feet of earth was then banked over the outside edges of the pit to give a total wall height of 8 feet. Large pipes were placed around the pit to furnish oxygen to the flame. The pipes were buried on a slant extending from the pit floor level to the surface. Water level, ordnance positioning and etc. were identical to that of the pan.

With all conditions favorable, personnel were called into shelter and a countdown began. At time zero the fire was started by remotely detonating 4 thermite grenades (or powder bags), placed one in each corner of the test pan. Also, at this time, all temperature and time recording equipment was started. The tests were visually observed for complete flame engulfment and time to reaction. Observations can be made on a closed circuit TV receiver located in the shelter. One of the required parameters for a successful test is an average flame temperature of 1650°F or greater. This temperature was determined by averaging flame temperature from the time the flame reached 1000°F until it dropped below 1000°F or until there was a reaction.

INSTRUMENTATION

Instrumentation consisted of motion picture and still camera coverage, pressure measurements to help determine severity of reactions, and temperature measurements of the flame at the ordnance. When physically possible, thermocouples were placed at the ordnance interface (between body and explosive or propellant) to determine (1) the origin of reaction, (2) temperature rise rate during heating, and (3) temperature present at the time of reaction.

Two motion picture cameras were positioned (behind fragment shelters) 90° apart and up wind of the test area. Camera rates were set to 24 and 96 frames per second. Black and white stills were made before and after each test.

Piezoelectric lollipop pressure gauges were positioned 50 feet or more (depending on the amount of explosive) from the ordnance under test at 4 different locations to measure the pressure wave.

Iron-constantan thermocouples (AWG #26 manufactured by Leeds and Northrup Co.) were used to measure both external and internal temperatures. The external thermocouples were placed in a horizontal plane coincident with the centerline of the ordnance being tested. Four thermocouples were used, one at each end and one at each side, six inches from the motor. Thermocouples placed internally were held in place (between the ordnance body and explosive or propellant) with small strips of Scotch Brand Aluminum tape. A constant temperature electric oven was used to generate the 150°F used as a reference for all temperature measurements. Data was recorded on linegraph paper from continuous recording oscillograph recorders. Sixty-cycle frequency filters were utilized to reduce extraneous readings.

DEFINITION OF REACTIONS

Definitions of reactions for general purpose bombs, cluster bombs, warheads, and aircraft gun ammunition are given in NAVORD OP5 Volume 1, Third Revision. Rocket and missile motor reaction definitions are presented in NWL Technical Report TR-2508 "Rocket Motor Survivability in Fire" of November 1970. Pyrotechnic and fuel tank reactions are not defined but classified as to the degree of hazard resulting when they are exposed in a fire environment.

RESULTS AND CONCLUSIONS

It was concluded from early tests that Comp-B explosive loaded bombs reacted sooner and at a higher order than did TRITONAL or H-6 explosive loaded bombs. Consequently, Comp-B loaded bombs were removed from aircraft carrier use. Table 1 is a summary of the general purpose bombs test results. Two tests were conducted on the all-up antitank bomb cluster MARK 20 MOD 2 (ROCKEYE II). In test No. 1 the bomb cluster container melted releasing the bomblets within the first minute of flame engulfment. At 1 minute 57 seconds the bomblets began reacting sporadically, with reactions ranging from deflagration to detonation. The reactions continued for 18 minutes. It was determined from post-test examination that approximately 100 of the 247 bomblets had reacted. The remainder were submerged under water in the cook-off pit. In test No. 2 most of the water was removed from the pit so that the bomblets would remain exposed in the flame environment. In this test the bomb cluster melted releasing the bomblets within the first minute of flame engulfment. At 1 minute 13 seconds the bomblets began reacting much the same way as in test No. 1. The post-test count revealed that approximately 200 of the

bomblets had reacted. In both tests parts of the ROCKEYE II and bomblets were recovered 225 feet from the test site. Four MARK 77 fire bomb tests were conducted and in every case the bombs melted or ruptured releasing NAPALM prior to fuze and/or igniter reactions. The released NAPALM increased the fire and the exploding fuze/igniter created a fragment hazard. (See Table 2 for additional data.) By far the most hazardous reaction noted was the detonation of general purpose bombs which create a hazard to personnel, adjacent aircraft and other ordnance on the flight deck. The ROCKEYE bomblets also create a fragment hazard up to 225 feet from point of reaction.

In most cases missile and rocket motors were tested separately from their warheads. NWL Technical Report TR-2508 of November 1970 entitled "Rocket Motor Survivability in Fire" is a complete accounting of all motor testing. A summary of results is presented as Table 3. Generally the most hazardous motor reactions were the STANDARD ARM motor which exploded; solid propellant BULLPUP motor that went propulsive; 5.0 ZUNI motor that partially detonated; PHOENIX motor that reacted in violent burning and the 2.75 FFAR all up (with warhead) round in LAU-69 Launcher which detonated. Each of these motors reacting in a fire creates a hazard to personnel, other ordnance, adjacent aircraft and any items in the area. In addition, the burning propellant enhances the existing fire and could kindle new ones in the area. Warhead tests are now being conducted and should be completed this year.

Generally, the smaller pyrotechnics, when exposed in a fire environment, react in their design mode. That is, they burn as designed but because of their size do not create any major hazard.

However they may present a problem to fire-fighting personnel in trying to extinguish them. These smaller pyrotechnics such as photoflash cartridges, aircraft parachute flares, marine location markers, illumination signals, aircraft smoke signals, guided missile flares, aircraft flares and decoy flares react in as short a time as 20 seconds after exposure to flame. Several tests were conducted with photoflash cartridges (52) loaded in pods. This kind of a situation resulted in a more violent reaction creating hazardous fragmentation in 2 minutes 16 seconds.

Although external aircraft fuel tanks are not weapons they were considered in the program because of their obvious hazard of feeding the existing fire. Fuel tanks of 300 (AERO 1-D and 600 (ATP-H4) gallon capacity of jet aircraft fuel (JP-4 and JP-5) were tested. Fuel loads of from 10% full to 100% full were considered. None of the tanks exploded or reacted violently. The tanks generally melted from 28 seconds to 15 minutes (depending on % and amount of load) after exposed in flames and spilled their fuel load, increasing the area of fire.

Analysis of time-temperature data and examination of test films of the MARK 4 gun pod test show that the aluminum pod body began to melt approximately 1 minute after start of test. The 20mm ammunition in both gun pods tested reacted similarly. Multiple as well as single reactions occurring indiscriminately were observed. They began 2 minutes 10 seconds and 2 minutes 21 seconds after start of fire for test 1 and 2, respectively. These reactions continued for approximately 12 minutes. Ammunition in the feed chutes was the first to react.

Pod debris and ammunition components were thrown distances of up to 270 feet from the test site. The most severe projectile reaction observed was a deflagration. The most common reaction was the initiation of the propellant charge in the cartridges. It is concluded that the MARK 106 MOD 2 HEI ammunition used in the pod presents a major hazard to personnel, aircraft, ordnance and other equipment when the pod is exposed in a fire. Mines and torpedoes are scheduled for testing but the effort has not yet commenced.

HEATING AND COOLING TESTS

Special fast cook-off tests were conducted to determine temperature rise rates and cooling rates of ordnance during and after their exposure to fire. A test pan was constructed allowing the fire to be removed when desired. This was accomplished by designing a pan with a 10° sloping bottom and with a remotely controlled drop gate at its lowest end. Water was added to the pan until a level surface 24 x 24 feet was obtained, and the JP-5 fuel was then floated on this surface. An instrumented, inert bomb (MARK 80 series) was suspended above the fuel surface and the fire ignited. The bomb is instrumented to record internal temperature at 90° intervals around the nose, center, and tail sections. When the bomb under test reached the desired temperature, or a specified amount of time had elapsed, the gate was remotely dropped, releasing water and burning fuel into a reservoir some distance from the test site. It was determined that an interface heating rate of from 4°F to 5°F per second occurs in an engulfing flame where the temperature average is approximately 1800°F.

Once the flame was removed from the bomb an air cooling rate at the interface of 0.4°F/sec was recorded.

Both water and LIGHT WATER, an organic fire extinguishing agent, were used in the cooling tests. The first evaluation was that of the NBC wash down system currently installed on carriers, the object being to determine if the system could be used for ordnance cooling during a conflagration. In the first tests flush deck nozzles were positioned directly under the bomb. In this configuration the center water plume of the nozzle impingea on a small area of the bomb. At the area of impingement, cooling took place but elsewhere on the bomb the internal temperature continued to increase at a normal rate. In the remaining test the nozzles were positioned on either side, 10 feet away and perpendicular to the bomb. These tests were designed to simulate ordnance ideally positioned between two nozzles with the side spray of each impinging on either side of the bomb. In this configuration no cooling of the bomb took place.

Water cooling tests employing a 1-1/2 inch hand held water hose delivering 60 to 95 gpm were conducted. It is concluded that when water is applied to the bomb's surface at an angle of from 10° to 50° to the nose, the bomb may be cooled at the rate of approximately 5°F/sec. In all tests where water was properly and continually applied, internal bomb temperatures stabilized at approximately 110°F. This is well within the safe region. Internal temperatures above 250°F are considered critical. When the same tests previously mentioned were conducted with LIGHT WATER no adequate cooling of the bomb was experienced, however, the LIGHT WATER was extremely effective in putting out the fires.

HOT DROP TESTS

Hot drop tests were conducted to determine if a bomb exposed in a simulated carrier deck fire would react on impact when ejected onto the flight deck in this heated condition. Bombs were suspended by a steel cable 9 feet above the fuel surface. Two inches below the fuel surface was a steel plate that simulated the carrier deck. After the bomb was exposed in the fire for 2 minutes (interface temperature approximately 250°F) it was remotely released by means of a cable cutter and allowed to strike the steel plate in its heated condition. In no case did a bomb react on impact.

EJECTION CARTRIDGE TESTS

Fast cook-off tests were conducted with triple ejector racks (TER) loaded with live ejection cartridges and inert bombs. The purpose of these tests was to determine if the bombs would be ejected because of cartridge cook-off. Since the TER racks are made primarily of aluminum, they melted allowing the bombs to fall free. Later, when cartridge cook-off did occur, the reaction was so mild that it did not trigger the ejection mechanism.

FUTURE PLANS

Testing will continue with an emphasis on eliminating the smoke polution problem of burning jet fuel. Instrumentation is constantly being improved with new time detection techniques employed to determine what section of the ordnance reacts first. The all up missile configuration will be tested to determine the effects of one section on the other. In order to determine safe stand-off distances for ordnance from a fire, cook-off characteristics of weapons in close proximity to a flight deck fire will be established.

TABLE 1

BOMB FAST COOK-OFF SUMMARY

Number Tested	Bomb	Load	Mean Reaction Time (sec)	Shortest Reaction Time (sec)	Type of Reaction(1)
13	MARK 81	H-6	152	110	Explosion and deflagration
3	MARK 81	Tritonal	155	116	Explosion and deflagration
2	MARK 81	Comp-B	125	115	Explosion
9	MARK 82	H-6	180	124	Explosion and deflagration
2	MARK 82	Tritonal	180	176	Deflagration
2	MARK 82	Minol	203	198	Deflagration
3	MARK 83	H-6	173	152	Deflagration
2	MARK 83	Tritonal	187	176	Deflagration
5	MARK 84	-6	223	182	Deflagration
4	MARK 84	Tritonal	249	203	Deflagration
4	M117	H-6	202	180	Deflagration
4	M117	Tritonal	239	175	Deflagration
2	M117	Com-B	127	120	Detonation

(1) Definitions provided in NAVORD OP5 Volume 1.

Table 2

Fire Bomb Fast Cook-Off Summary

Test	Fire Bomb	Fuze	Igniter	Time to First Reaction (sec)	Results(1)
1 of 2	MARK 77 MOD 2	M173A1	AN-M23A1	165	Fuze/igniter exploded. At 179 seconds, other fuze/igniter assembly exploded. Both reactions resulted in fragmentation. NAPALM increased fire.
2 of 2	MARK 77 MOD 2	M173A1	AN-M23A1	156	Fuze/igniter exploded. At 183.5 seconds, other fuze/igniter assembly exploded. Both reactions resulted in fragmentation. NAPALM increased fire.
1 of 4	MARK 77 MOD 4	M918	MARK 273-0	210	Fuze/igniter exploded. Reaction resulted in fragmentation. Other fuze/igniter assembly did not react. NAPALM increased fire.
2 of 4	MARK 77 MOD 4	M918	MARK 273-0	199	Fuze/igniter exploded. At 210 seconds, other fuze/igniter assembly exploded. Both reactions resulted in fragmentation. NAPALM increased fire.
3 of 4	MARK 77 MOD 4	MARK 343-1	MARK 273-1	342	Igniter exploded. Fuze did not react. At 444 seconds, other fuze/igniter assembly exploded. All reactions resulted in fragmentation. NAPALM increased fire.
4 of 4	MARK 77 MOD 4	MARK 343-1	MARK 273-1	301	Igniter exploded. At 361 seconds, the fuze exploded. At 750 seconds, other fuze/igniter assembly exploded. All reactions resulted in fragmentation. NAPALM increased fire.

(1) In all tests the fire bombs melted or ruptured releasing NAPALM prior to fuze and/or igniter reactions.

Table 3

Rocket Motor Fast Cook-Off Summary

Test	Motor	Time to Reaction (sec)	Reaction(1)
1 of 2	MARK 1 MOD 0 STANDARD ARM	68	Chuffing followed by explosion.
2 of 2	MARK 1 MOD 0 STANDARD ARM	60	Deflagration followed by propellant burning.
1 of 4	MARK 17 MOD 1 SIDEWINDER	65	Chuffing followed by motor breaking up.
2 of 4	MARK 17 MOD 1 SIDEWINDER	72	Chuffing, then motor melted apart.
3 of 4	MARK 36 MOD 5 SIDEWINDER	90	Mild deflagration followed by propellant burning.
4 of 4	MARK 36 MOD 5 SIDEWINDER	60	Mild deflagration followed by propellant burning.
1 of 6	LR-58 BULLPUP (Liquid Propellant)	105	Acid cloud followed by burning and deflagration.
2 of 6	LR-58 BULLPUP (Liquid Propellant)	362(2)	Small visible flash and audible noise.
3 of 6	LR-62 BULLPUP (Liquid Propellant)	125	Acid cloud followed by explosion.
4 of 6	LR-62 BULLPUP (Liquid Propellant)	90	Explosion.
5 of 6	MARK 8 MOD 1 BULLPUP (Solid Propellant)	93	Chuffing, then went propulsive.
6 of 6	MARK 8 MOD 1 BULLPUP (Solid Propellant)	149	Chuffing, then went propulsive.
1 of 8	MARK 52 MOD 1 SPARROW	63	Deflagration, propellant ejected and burned.
2 of 8	MARK 52 MOD 1 SPARROW	75	Deflagration, propellant ejected and burned.
3 of 8	MARK 38 MOD 0 SPARROW	95	Deflagration.
4 of 8	MARK 33 MOD 0 SPARROW	101	Deflagration.
5 of 8	MARK 6 MOD 3 SPARROW	85	Motor burning followed by deflagration.
6 of 8	MARK 6 MOD 3 SPARROW	150	Deflagration.
7 of 8	MARK 6 MOD 3 SPARROW	141	Deflagration.
8 of 8	MARK 6 MOD 3 SPARROW	149	Deflagration.
1 of 2	2.75 FFAR Motor	76	Deflagration (Mild).
2 of 2	2.75 FFAR Motor	58	Deflagration (Mild).
1 of 2	5.0 FFAR Motor	90	Partial Detonation.
2 of 2	5.0 FFAR Motor	79	Partial Detonation.

Table 3 (continued)

Rocket Motor Fast Cook-off Summary

Test	Motor	Time to Reaction (sec)	Reaction(1)
1 of 1	MARK 47 MOD 0 PHOENIX	322	Chuffing followed by deflagration and violent propellant burning.
1 of 2	MARK 67 MOD 0 ZAP	44	Explosion.
2 of 2	MARK 67 MOD 0 ZAP	36	Explosion.
1 of 2	AQM 37A Target Drone	64	Deflagration.
2 of 2	AQM 37A Target Drone	90	Deflagration.
1 of 2	2.75" FFAR In LAV-69 Launcher	265	Detonation of warheads; deflagration of motors.
2 of 2	2.75" FFAR In LAV-69 Launcher	150	Detonation of warheads.
1 of 2	5.0" ZUNI In LAV-10/A Launcher	115	Deflagration of warheads and motors.
2 of 2	5.0" ZUNI In LAV-10/A Launcher	180	Deflagration of warheads and motors.
1 of 2	MARK 53 MOD 3 SHRIKE	45	Deflagration (Mild).
2 of 2	MARK 53 MOD 3 SHRIKE	75	Deflagration.

(1) The terms detonation, partial detonation, explosion and deflagration as used here are in accordance with the definitions provided in NWL Technical Report TR-2508 of November 1970.

(2) An initial reaction possibly occurred much sooner but would not be detectable because of the fire and smoke engulfing the motor.

INCREASE COOK-OFF TIME OF NAVAL WEAPONS

by

Richard A. N. Larson
and
Richard W. Slyker
Naval Missile Center
Point Mugu, California

The aircraft carrier USS FORRESTAL, experienced a disasterous flight deck fire during deployment in 1967. The fire was initiated by an accidentally fired rocket which struck an aircraft, ruptured its fuel tanks and ignited the fuel. Approximately ninety seconds later, a bomb exploded because of "cooking" in the fire, dispersing the first contingent of fire fighters and spreading the conflagration to adjoining aircraft. The fire spread rapidly and caused other ordnance to detonate increasing the fire and rupturing the flight deck allowing the burning fuel to spill into lower decks of the carrier including crew quarters.

The Chief of Naval Operations appointed a committee headed by Admiral Russell(Ret.) to investigate the USS FORRESTAL disaster and other less serious aircraft carrier accidents.

The committee investigated and analyzed all aircraft carrier operations with the objective of decreasing the possibility of future carrier accidents. Recommendation 4.1 of the Russell Report said in part, "means to increase cook-off times should be developed and applied to current and future weapons." A cook-off time improvement program for naval aircraft weapons was implemented to fulfill this recommendation. The urgency of implementing the Russell Report recommendations was further emphasised by the catastrophic flight deck fire aboard the USS ENTERPRISE in 1969.

The first weapon under initial consideration for cook-off time improvement was the MK 82 general purpose 500 pound bomb. The weapon was identified because of the bomb's high usage rate, destructive power and short cook-off time.

A two part program was initiated to increase the cook-off time of the MK 82 bomb. The first part was the "Quick Fix"

PRECEDING PAGE BLANK

program which had an objective of providing the MK 82 bomb with an increased cook-off time without conducting lengthy qualification tests. Results of this program yielded a five minute versus three minute cook-off time for the MK 82 bomb. This time improvement resulted from an exterior intumescent paint and an increased thickness of the interior asphalt liner. After introduction into the Fleet, however, it was found that the hot humid climate in the area of operations degraded the effectiveness of the intumescent paint. This paint was discontinued from further production although a minimum of four minute cook-off time had been achieved because of the increased thickness of the interior asphalt liner.

The second part of the bomb cook-off program had the objective of providing the Fleet with a fully qualified, five minute minimum protection time to the MK 82 bomb. Qualification was to insure the protection system would withstand all the rigors of world wide environmental exposure including: shipping, handling, storage, safety, and flight.

The NAVAIR (Naval Air Systems Command, Headquarters) assigned the Naval Missile Center, Point Mugu, as the lead field activity responsibile for the BCOIP (Bomb Cook-Off Improvement Program).

A BCOIP Committee was established in September 1969 to implement this program. The committee was composed of representatives from various naval activities. The fields covered by this committee included thermal stability, explosive compatability, paint formulation/application, test and evaluation, instrumentation, production, engineering and program management.

The BCOIP was divided into three phases which included requirements definition and material evaluation; prequalification and qualification of thermal protective systems applicable to the MK 82 bomb.

Phase I established guide lines for determining acceptable thermal protective systems and established design limits. A request was issued to industry and other government agencies to submit thermal protective systems for consideration that would satisfy the thermal, environmental, physical, chemical, application and producibility requirements. Exterior systems were limited to a thickness of .150 inch while interior systems were allowed .250 inch thickness. Protective systems were required to be applied in less than two minutes, have a short cure time, and not exceed a maximum cost limitation.

Forty protection systems were submitted by both industry and government agencies. Of these, ten were considered feasible by the BCOIP committee and were selected for further evaluation.

Phase II was designed to evaluate the ten materials on a limited test basis. The thermal materials were subjected to small scale physical, environmental and thermal tests, full scale cook-off tests, and evaluation of production, application, handling, storage and unit cost. Based on the above tests and evaluations, only three of the ten materials exhibited the potential for obtaining the five minute minimum cook-off times. Two materials were exterior coatings that were applied by spraying on a thickness of .150 inch and .100 inch. The third internal coating which replaced the asphalt liner.

The final phase of the BCOIP was designed to qualify the three protective systems identified in Phase II. A series of qualification tests were defined to insure that the protective system would not degrade under the environments to which the bomb is exposed. In addition to the qualification tests, the physical properties of the thermal protective materials were fully defined.

Qualification tests included WR-50 safety, ship suitability, flight, explosive compatability, carrier suitability and cook-off time definition.

The WR-50 safety tests included 28 day temperature and humidity cycling, salt spray, fungus growth, aircraft and transportation vibrations, handling drops and cook-off of the environmentally tested bombs. Over 100 bombs were utilized in the qualification portion of the program.

Of the three materials subjected to qualification only one exterior material satisfied all the tests. The internal material showed questionable explosive compatability and difficult application control. One external coating failed the 28 day temperature and humidity cycle in that the coating softened and was degraded by the subsequent aircraft and transportation vibration tests.

The qualified thermal protective system has been approved for service use. It consists of an .150 inch thick exterior coat of an ablative type filled-polyester insulation material, an increased thickness of the asphalt liner and a polyermerized asphalt bomb base pad. The functions of each material are as follows:

The external coating provides the thermal protection, the increased asphalt liner insures a deflagration reaction and increases the cook-off time, and the polermized asphalt base pad prevents cook-off initiation at the base of the bomb. This system increases the cook-off time of the MK 82 bomb from three minutes to over nine minutes and insures a deflagration type reaction. The nine minute minimum cook-off time is not degraded

by the environments to which the bomb is exposed.

In addition to the thermal protection systems developed for the MK 82 bomb, protection systems were also developed for the M904 mechanical bomb nose fuse and M148 bomb adapter booster, fuse and adapter booster thermal protection was required because, without protection, a fuse/adapter booster reaction occurring first would cause a high order reaction. The standard M904 fuse cooks-off in approximately five minutes and M148 adapter booster in four minutes. The objective of the fuse program was to increase these times to a minimum of 12 minutes. ' program similar to the BCOIP was set up to identify possible protection concepts, test the more feasible concepts and qualify these for Navy use.

Approximately 15 materials were identified for thermal protection of fuses. Four were selected for full scale testing after a number of small scale tests were performed for thermal, physical and environmental requirements.

The four selected materials were fabricated into sleeves which fit over the outside of the fuse and were tested in the specification fire. Upon completion of the initial test, it was determined that in addition to the sleeve, the front face of the bomb required protection to meet the 12 minute minimum time objective of the program. Further testing of the four materials identified two systems for qualification.

The M148 adapter booster was found to react in a short time when exposed to a wind whipped fire in the open condition, i.e. without the fuse installed. This situation is often found on the flight deck. Two solutions were identified and tested to extend the cook-off time of the adapter boosters. These included a coating of intumescent paint on the boosters interior and the use of phenolic heat path interrupters.

The qualification phase of the fuse program included functional, environmental transportation, flight, cook-off and handling tests. Upon successful completion of these tests, the thermally protected M904 fuse and M148 adapter booster were approved for production and service use. The qualified M904 fuse thermal protection consisted of a acranitryle butadine rubber sleeve which was fastened to the outside of the fuse with an adhesive. The adapter booster thermal protection consisted of a phenolic washer and disc which interrupts the direct heat path through the aluminim sleeve inside the booster. These protection systems extend the cook-off time of the fuse and adapter booster from approximately five minutes to 12 minutes plus allowing the bomb to react first resulting in a lower order reaction.

In addition to the above weapons, the Navy is presently qualifying thermal protection systems for the MK 83, 1000 pound and MK 84, 2000 pound low drag general purpose bomb and their associated bomb fuses.

Programs are presently in progress which will increase the cook-off time of other naval weapons. These programs include air launched rockets, air launched missiles and aircraft guns.

Through these programs, the cook-off times of in-service naval air weapons will be increased. This additional ordnance cook-off time will allow the ships force to extinguish aircraft carrier deck fires prior to ordnance cook-off and help prevent disasterous effects as experienced aboard the USS FORRESTAL and USS ENTERPRISE.

ANALYTICAL MODEL
FOR HIGH EXPLOSIVE MUNITIONS STORAGE

by
L. E. Romesberg

Albuquerque Division
MECHANICS RESEARCH, INC.
1200 University Square, NE
Albuquerque, New Mexico 87102

PRECEDING PAGE BLANK

ANALYTIC MODEL
FOR HIGH EXPLOSIVE MUNITIONS STORAGE

1. INTRODUCTION

Storage of large quantities of munitions have required the use of considerable amounts of real estate to insure the safety of personnel and nearby materiel. If munitions storage clearance requirements could be reduced without endangering safety requirements, significant economic gains could be realized.

Full scale tests of munitions storage concepts have been conducted and have yielded valuable information leading toward more rational munitions storage criteria. Such tests are, however, expensive and exceedingly time consuming. Availability of analytical procedures which could be used with some confidence to predict the detonation effects for a stack of munitions would be invaluable in analyzing new storage concepts, or in rational, effective planning of future full scale tests.

Effects produced by the accidental explosion of a munition storage area which are significant regarding possible damage to personnel and nearby materiel or possibly sympathetic detonation of adjacent stacks of munitions should be considered. Included in these effects are

- peak overpressure,
- unit impulse,
- mass and velocity of fragments and their distribution,
- crater dimensions,
- ejecta distribution.

Analytical models which adequately predict these effects and supply a first step toward development of the complete analytical model necessary to perform the analysis discussed above are outlined herein.

Throughout the analytical models, results of large and small scale tests were used to describe phenomena. In addition, the use of basic principles implies that new situations can similarly be predicted on a rational basis. The models are constructed to easily incorporate results from new experimental and theoretical works as they become available.

2. BLAST EFFECTS

In this section the effects of various individual properties of the munition stack on peak overpressure and positive impulse are outlined. The variables considered were

- presence of a weapon case,
- stack geometry,
- a barricade surrounding as explosive stack.

The approach followed was to develop a model to predict pressure and impulse for a hemispherical surface stack of TNT as functions of scaled distance (Z), and then modify these relationships to account for the above variables. Scaled distance, Z, is defined to be the distance R(ft) from the point of detonation divided by the equivalent charge weight of explosive in pounds of TNT to the one-third power $W^{1/3}$.

$$Z = R/W^{1/3} \tag{1}$$

Similarly, the scaled positive impulse (I) to be considered is defined as the positive unit impulse (i_s) divided by the equivalent charge weight of explosive in pounds of TNT to the one-third power $W^{1/3}$.

$$I = i_s/W^{1/3} \tag{2}$$

a. Bare Charge Parameters

Reliable curves for peak overpressure and scaled positive impulse as a funciton of scaled distance have been developed from the many tests performed in the past. Variations do appear in the curves available in the literature from different agencies, but the differences are very small. The relationships selected for the development of the basic model (See Figure 1) are published in Reference 1.

The equations for these two curves were required for the mathematical model. To obtain the desired equations, points on the P-Z and I-Z curves were selected and the coordinates of these points transformed by computing their natural logarithms for use in a least squares polynomial curve fit program to obtain relationships of the form

$$\ln P = a_o + a_1 (\ln Z) + a_2 (\ln Z)^2 + \ldots \tag{3}$$

$$\ln I = b_o + b_1 (\ln Z) + b_2 (\ln Z)^2 + \ldots \tag{4}$$

The resulting coefficients for an eighth order polyomial which very accurately fit the desired curves are given in Table I.

b. Case Effect (bombs)

Placing cased explosives in the munition stack has the effect of reducing the magnitude of the peak overpressure and scaled positive impulse due to the energy required to rupture the case and accelerate fragments. In the model this effect was accounted for by the use of a bomb factor. This factor is multiplied by the total weight of explosive in the stack to yield an equivalent weight of bare TNT. The bomb factor includes the confined explosion effect, the surface reflectivity, and the individual bomb geometry effect. Typical bomb factors can be

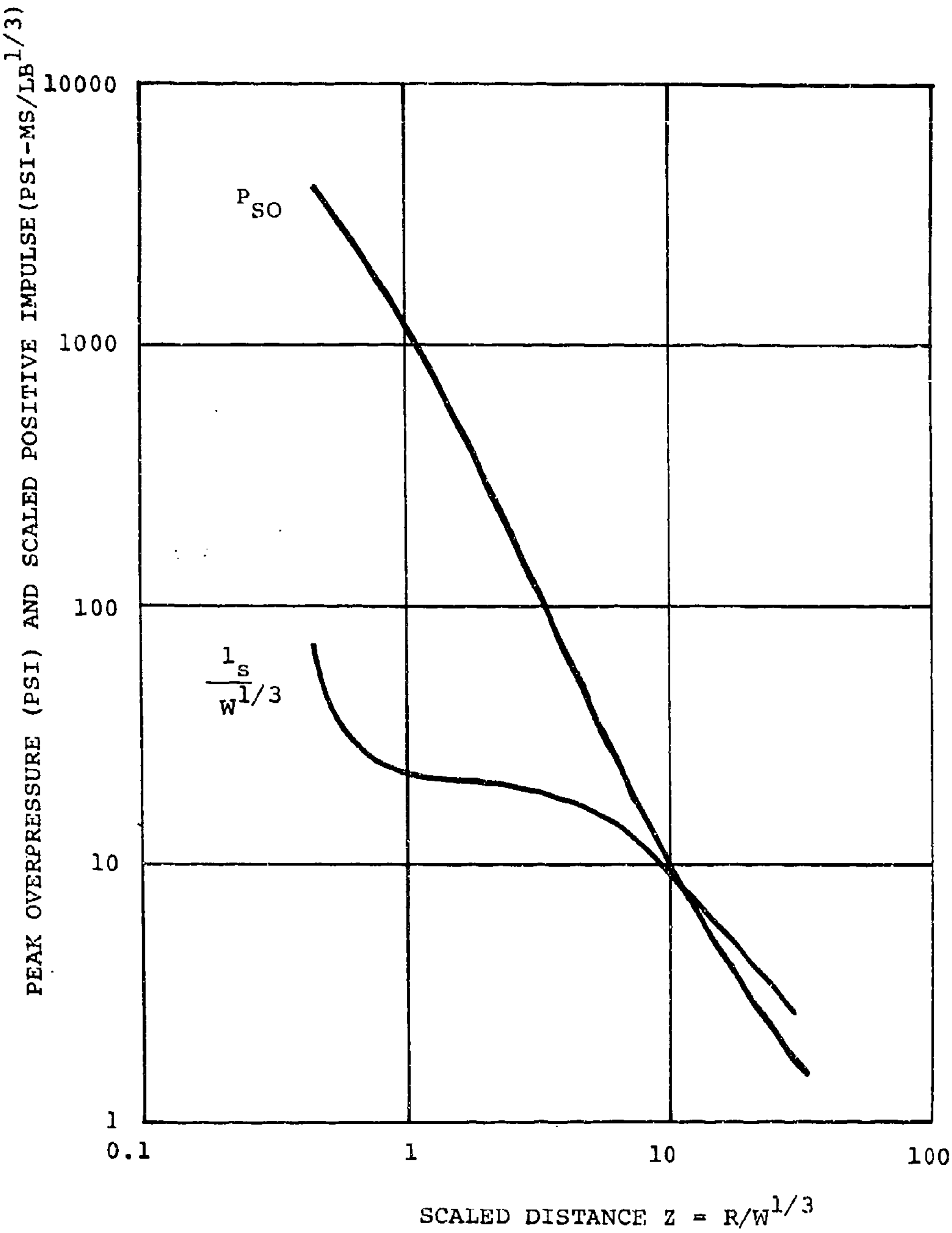


Figure 1. Shock Wave Parameters for Hemispherical TNT Surface Explosion a· Sea Level

TABLE I

POLYNOMIAL COEFFICIENTS FOR DETERMINING PEAK OVERPRESSURE AND SCALED POSITIVE IMPULSE FOR A BARE HEMISPHERICAL CHARGE

$$a_0 = 10.7036810 \times 10^{1}$$
$$a_1 = -0.1663724 \times 10^{1}$$
$$a_2 = -0.2516481 \times 10^{0}$$
$$a_3 = -0.1137714 \times 10^{0}$$
$$a_4 = +0.3818405 \times 10^{-1}$$
$$a_5 = +0.5035198 \times 10^{-1}$$
$$a_6 = -0.2756970 \times 10^{-1}$$
$$a_7 = +0.5557968 \times 10^{-2}$$
$$a_8 = -0.5108014 \times 10^{-3}$$
$$a_9 = +3.1795565 \times 10^{-4}$$

$$b_0 = +0.3129288 \times 10^{1}$$
$$b_1 = -0.1295979 \times 10^{0}$$
$$b_2 = +0.4112452 \times 10^{0}$$
$$b_3 = -0.7687394 \times 10^{0}$$
$$b_4 = +0.4969224 \times 10^{0}$$
$$b_5 = -0.1684197 \times 10^{0}$$
$$b_6 = +0.2805656 \times 10^{-1}$$
$$b_7 = -0.1791292 \times 10^{-2}$$

found in Reference 2. Since there were apparently no empirical or theoretical data available to predict the explosion confinement effect caused by stacking munitions, this effect was not included.

c. Stack Geometry Effect

The effect of the geometric shape of the munitions stack is known to have a large affect on peak overpressure and impulse near the point of detonation and to decrease with distance. Documentation of the magnitude of this effect in the current literature is minimal.

One document (Reference 3) contains test results for eight different shapes composed of 50 pounds of RDX composition C-3 explosive. This charge weight is equivalent to 54.5 pounds of bare TNT. It was assumed that a typical stack of munitions could be approximated by rectangular stacks. The dimensions of the

cube considered in Reference 3 and in this study were 9.6 in. per side while the plate dimension were 54.1 in. x 9.0 in. x 1.8 in. Pressure and impulse measurements were taken at ranges of 35 ft., 45 ft., 60 ft., 70 ft., and 80 ft. from the center of the charge along lines perpendicular to the center of each face and along lines through the edges and charge center in a horizontal plane for the cube. These ranges correspond to scaled distances of 9.22, 11.85, 15.8, 18.43, and 21.06 ft/lb$^{1/3}$, respectively. The ratio of the measurements for the rectangular charges divided by the measurements from the spherical charge, also reported in Reference 3, were used. In other words, the model deals with the effect of going from a spherical charge to a rectangular charge rather than dealing with the rectangular charge at face value.

A parametric study of the data indicated that a reasonable approach to the model development would be to analyze the data according to an "area ratio" scheme. Theoretical justification for this approach was not available but the results approximate available test data accurately. By this method, the energy delivered in a direction perpendicular to the center of an exposed face is proportional to the ratio of the area of that face divided by the total charge surface area exposed to the atmosphere. This ratio is referred to as the "face area ratio" (FAR), and is computed for direction P_1, as follows (see Figure 2):

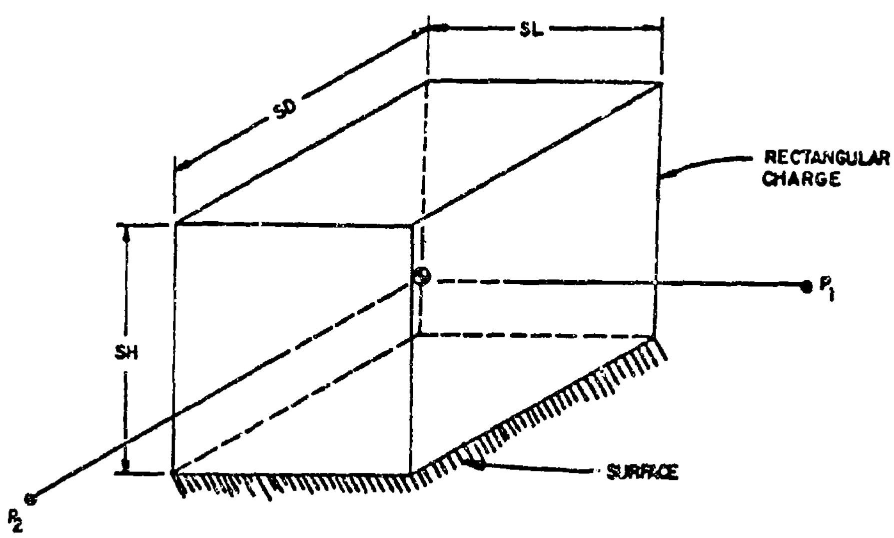


Figure 2. Bomb Stack Dimensions

$$FAR_{P_1} = \frac{SH \times SD}{2(SH \times SD) + 2(SH \times SL) + (SL \times SD)} \quad (5)$$

The magnitude of FAR will always be greater than zero and less than one half.

At each range R, or scaled distance Z, a relationship between pressure or impulse ratio and FAR was established from the data obtained from Reference 3. The form of these relationships is as follows:

$$\frac{P}{P_{sphere}} = B + C\ (FAR) + D\ (FAR)^2 \quad (6a)$$

$$\frac{I}{I_{sphere}} = F + G\ (FAR) + (FAR)^2 \quad (6b)$$

The coefficients B, C, D, F, G, and H were solved for values of Z from polynomials of the form

$$B, C, D, F, G, H = C_0 + C_1 Z + C_2 Z^2 + C_3 Z^3 + C_4 Z^4 + C_5 Z^5 \quad (7)$$

Coefficients to these fifth order approximating polynomials were determined by a least squares polynomial curve fit program. The coefficients resulting from this curve fit procedure are presented in Table II. A note of warning may be advisable at this time to point out the possiblility of erroneous approximations for values of Z less than 9 because of the lack of data in this region.

Relationships for pressure and impulse out the edge of the cube as functions of scaled distance were also determined. At each of the scaled distances listed previously, the ratio of edge to face peak overpressure ratio and positive impulse ratio was determined for the cube. The results were put into a least squares polynomials curve fit program to obtain the coefficients for the polynomials in Z. The results of this analysis are shown in Table III.

To predict edge overpressures and impulses for stacks which are not cubes, the ratio for the cube was multiplied by the average pressure and impulse off the adjacent faces for the same scaled distance. Determination of pressure and impulse values for directions between those perpendicular to the faces and through the edges were approximated by linear interpolation (See Figure 3).

d. Barricade Effect

The effect of a standard rectangular three sided barricade surrounding a charge is shown in Figure 4. This figure, taken from Reference 1, is accurate for barricade length to depth ratios of about one and weight of charge, W, to volume of structure, V,

TABLE II

POLYNOMIAL COEFFICIENTS FOR B, C, D, F, G AND H

	C_0	C_1	C_2	C_3	C_4	C_5
B	19.9156	- 5.4922	0.5693	-0.0266	0.0006	0.0000
C	-161.9033	47.4129	-4.9886	0.2355	-0.0051	0.0000
D	272.6186	-77.9697	8.2005	-0.3888	0.0085	0.0001
F	5.9069	- 1.7159	0.2183	-0.0117	0.0003	0.0000
G	- 1.3016	4.6739	-0.9968	0.0645	-0.0017	0.0000
H	- 8.1686	- 4.9228	1.4370	-0.0910	0.0027	0.0000

TABLE III

POLYNOMIAL COEFFICIENTS FOR THE RATIOS
EDGE PRESSURE/FACE PRESSURE AND
EDGE IMPULSE/FACE IMPULSE

$$\frac{\text{EDGE PRESSURE}}{\text{FACE PRESSURE}} = \sum_{i=0}^{6} d_i \, Z^i$$

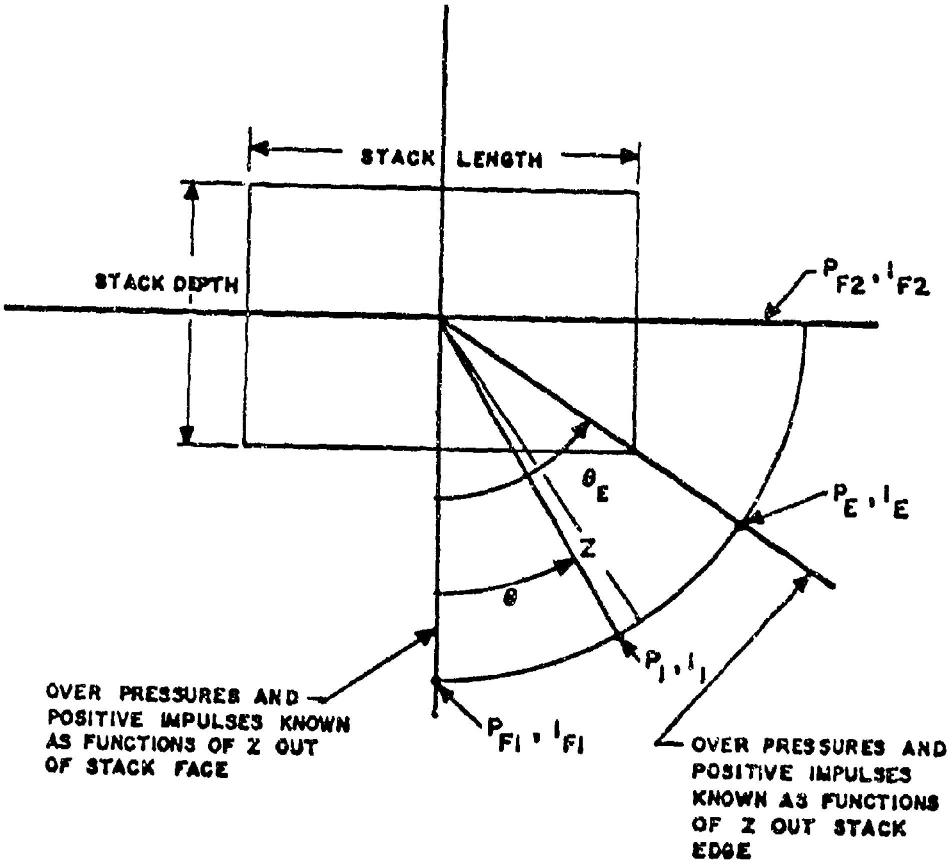
$d_0 = -0.5442047 \times 10^{-1}$
$d_1 = -0.3279577 \times 10^{-2}$
$d_2 = 0.3172064 \times 10^{-1}$
$d_3 = -0.2700095 \times 10^{-2}$
$d_4 = 0.8668014 \times 10^{-4}$
$d_5 = -0.1294399 \times 10^{-5}$
$d_6 = 0.7019624 \times 10^{-8}$

$$\frac{\text{EDGE IMPULSE}}{\text{FACE IMPULSE}} = \sum_{i=0}^{4} e_i \, Z^i$$

$e_0 = -0.3879756 \times 10^{0}$
$e_1 = 0.2953776 \times 10^{0}$
$e_2 = -0.1519496 \times 10^{-1}$
$e_3 = 0.2943603 \times 10^{-3}$
$e_4 = -0.1946069 \times 10^{-5}$

ratios (pounds of TNT/ft^3) in the range of 0.2 to 2.0. When dealing with very large or very small ratios of W/V the effect of the barricade can be neglected.

For the directions A, B, C, and D indicated in Figure 4, values were established for peak overpressure as a function of scaled distance. Each of these pressures was then divided by the corresponding value of peak overpressure for an unconfined surface burst at the corresponding distance. These point coordinates were put into a least squares polynomial curve fit program to obtain coefficients of fourth order polynomials in terms of scaled distance. The coefficients for the approximating polynomial are listed in Table IV. Because of the lack of similar data for positive impulse, the relationships derived for peak overpressure were also used for impulse predictions. To obtain the peak overpressure or positive impulse for a barricaded charge, the ratios obtained from the polynomials in Table IV were multiplied by the value of the peak overpressure or positive impulse from a bare charge at the same scaled distance. For directions other than those shown in Figure 4, the linear approximation technique illustrated in Figure 3 was applied.



$$P_i = \frac{\theta}{\theta_E}\,(P_E - P_{F1}) + P_{F1}$$

$$I_i = \frac{\theta}{\theta_E}\,(I_E - I_{F1}) + I_{F1}$$

Figure 3. Geometry Effect and Interpolation Technique

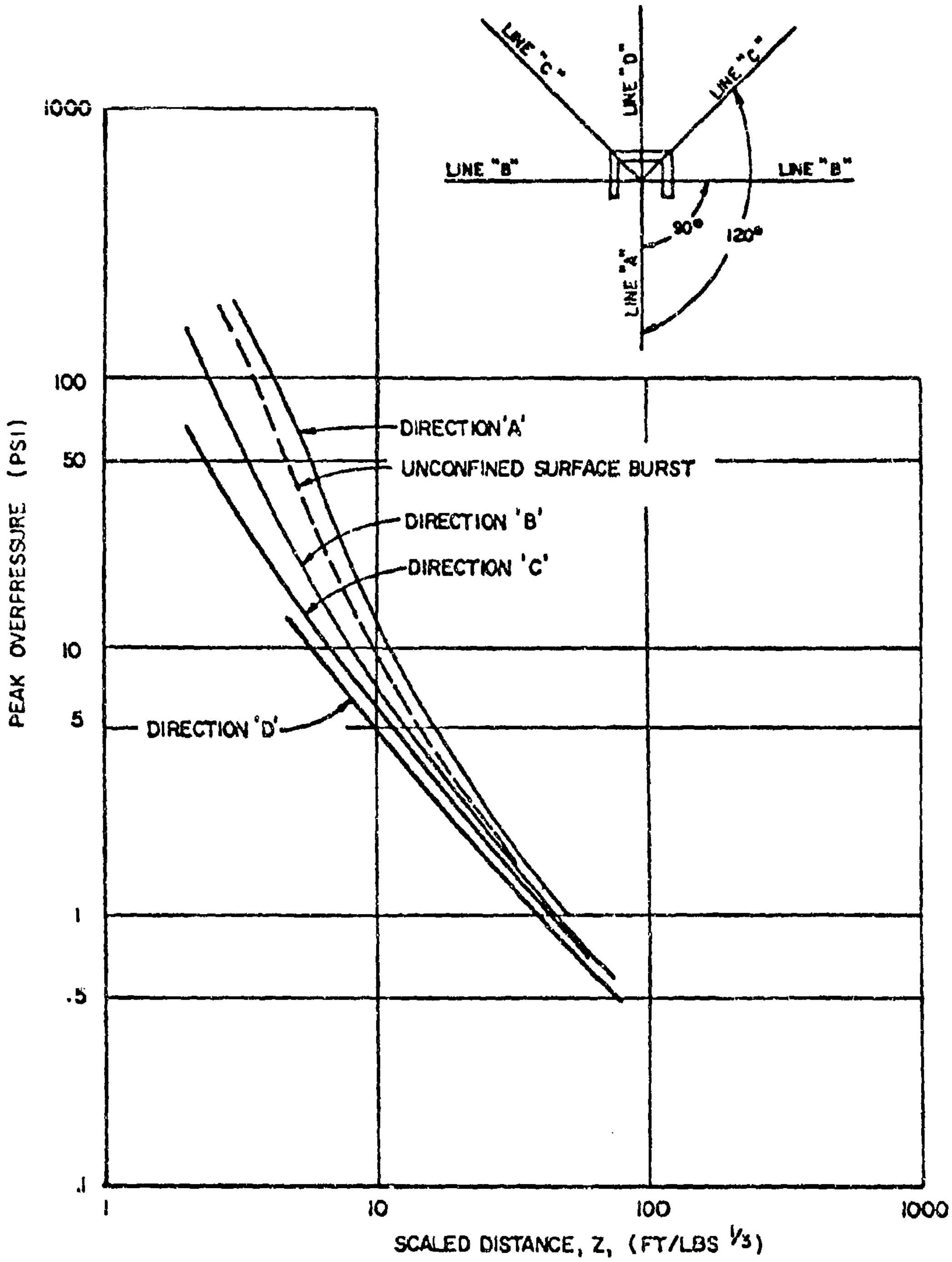


Figure 4. Exterior Leakage Pressure vs Scaled Distance

TABLE IV

POLYNOMIAL COEFFICIENTS FOR PRESSURE RATIO VS. Z POLYNOMIALS FOR BARRICADE EFFECT

Direction From Barricade Center	f_0	f_1	f_2	f_3	f_4
Out Barricade Open End (line A Figure 4)	0.156906×10^{1}	-0.255441×10^{-1}	0.514850×10^{-3}	-0.456934×10^{-5}	0.128127×10^{-7}
Out Barricade Side (line B Figure 4)	0.332731×10^{0}	0.491787×10^{-1}	-0.120238×10^{-2}	0.112170×10^{-4}	-0.317559×10^{-7}
Out Barricade Corner (line C Figure 4)	0.890016×10^{-1}	0.630056×10^{-1}	-0.151824×10^{-2}	0.141540×10^{-4}	-0.401201×10^{-7}
Out Barricade Back (line D Figure 4)	0.153318×10^{0}	0.394489×10^{-1}	-0.760448×10^{-3}	0.603386×10^{-5}	-0.155600×10^{-7}

$$\text{Pressure Ratio} = \sum_{i=0}^{4} f_i \, Z^i$$

3. FRAGMENTATION

The fragmentation analytical model considers the dispersions and patterns in terms of fragment velocities, weights, directions, and ranges for a single weapon and then adjusts the output for a stack of munitions.

a. Initial Conditions

Mathematical theories are available for predicting the initial fragment velocity and mass distribution, but they fail to predict how mass and number of fragments vary with direction from the weapon. Experimental results available in the literature provide accurate measures for number of fragments per steradian, average fragment mass, and initial velocity as functions of polar angle measured from the nose of the weapon (See References 4 and 5). The experimental fragment data were used exclusively instead of the theoretical approach.

b. Fragment Trajectories

The trajectory of fragments ejected from a single cased charge in a given direction was approximated by using the basic free-flight equations of mechanics in a finite difference form. The path of a typical fragment was represented by a finite number of linear segments. The initial conditions at the beginning of each segment are known from the previous step or the initial conditions. Along any given segment of the trajectory the direction of the fragment was assumed to remain constant. The coordinates at the end of a linear segment were approximated using the coordinates and velocity at the start of the linear segment. Forces acting on the fragment are shown in Figure 5. Included are the

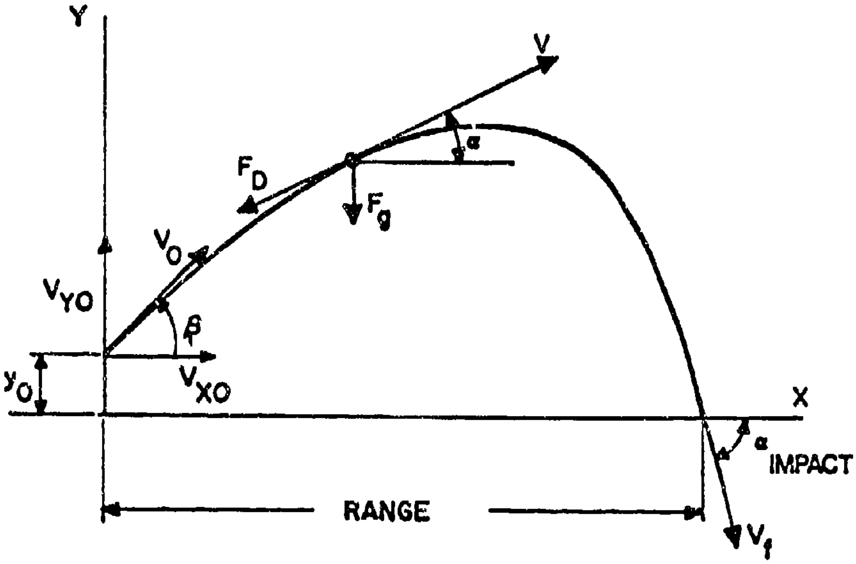


Figure 5. Trajectory of a Fragment

drag force, F_D, acting in the direction opposite to the direction of travel and the force of gravity. By assuming that the fragment shape can be closely approximated by a cube, the forces acting on the fragment were reduced to a function of the mass of the fragment. The velocity at the end of a linear segment was approximated from the change in velocity along the segment due to the drag force and the change in vertical velocity due to the gravity force. By considering successive segments, the velocity and coordinates of a fragment at impact were determined. If a fragment struck the barricade surrounding the stack, the fragment was assumed to be stopped by the barricade.

c. Fragment Distribution

A finite number of trajectories were computed using average fragment initial conditions to obtain a representative distribution. From the impact conditions (range, direction, velocity and number of fragments), the distribution was obtained by dividing the total number of fragments ejected by the approximate area impacted to yield fragments per unit area.

d. Stack Effect

The detonation of a stack of munitions will not yield a fragment distribution pattern equivalent to the detonation of the same number of single weapons due to interaction effects. The stack effect was determined by studying the fragment distribution from a number of experiments. Once determined, this "correlation factor" was multiplied by the distribution pattern for a single weapon to predict the pattern for a stack of munitions.

4. CRATERING AND EJECTA

Techniques have been devised to yield reasonable approximations for crater dimensions and ejecta distribution from the many explosive tests conducted in the past. The general trend has been to assume a nondimensional relation between characteristic dimensions of the crater and the explosive yield raised to some power. The resulting relationships, called scaling laws, must be modified to account for changes in geology before they are used to extrapolate to new regions of interest. Test shots such as those conducted at Suffield Experimental Station and "Operation Sailor Hat" have shown that any one scaling law produces reasonable results over a very limited range of explosive values.

In the absence of analytical work in this area, and because charge shapes in field tests are almost exclusively spherical or hemispherical, and whereas munition stacks are usually rectangular, it seemed appropriate to develop an elementary model using the basic principles of mechanics. As in the previous sections, the munition stack is assumed to rest on soil.

a. Basic Considerations

When an explosion occurs, the total available energy is divided into various categories: blast wave, heat and kinetic energy of the explosion products, to mention the more obvious ones. Apparently the blast wave does not contribute to cratering, but rather, it causes a shock wave to be instigated in the earth. The major source of cratering must then be the kinetic energy of the explosion products. By momentum transfer, energy is transferred to the earth media elements located on the surface and adjacent to the explosive, and by propagation within the neighboring region, earth particles are ejected and a crater is formed.

The fundamental assumptions upon which the analytical cratering model is based are (See Figure 6)

- Only the material in the bottom half of the charge below the plane Z=L contributes to the cratering phenomenon,
- all elements in the bottom half of the charge are directed vertically downward with identical speed,
- frictional force is constant,
- at the interface between the surface of the earth and the explosive, the loss of kinetic energy is negligible.

A cratering factor C_F can be defined as the ratio of the kinetic energy E_s reaching the surface to the total kinetic energy E_T available from the charge. This factor will vary with the charge configuration. Typical charge configurations are shown in Figure 7. For each configuration, comparisons between charges of different yields are possible only if the shapes are of the same geometric proportions. For cylindrical and triangular prisms, (which include rectangular parallepipeds), this implies that the base areas must be proportional to the square of the height.

In comparing the effects of charges with similar shapes it is convenient to use the nondimensional parameters

$$\begin{aligned} T &= W/W_o \\ K &= E_s/E_s^o \\ C_o^F &= C_F/C_{Fo} \end{aligned} \qquad (8)$$

where C_{Fo} and E_s^o are associated with a reference yield W_o. The kinetic energy available at the surface can be directly related

to the charge yield by the relation

$$K = C_o^F \quad T \tag{9}$$

For the set of configurations shown in Figure 7, it can be shown that

$$C_o^F = \frac{\left[2 - \left(\frac{W}{W_L}\right)^{1/3}\right]}{\left[2 - \left(\frac{W_o}{W_L}\right)^{1/3}\right]} \tag{10}$$

where W is the charge weight of interest and W_L is an equivalent charge of weight W whose CG is at height L above the surface. For the range of charge weights considered in this study, and the charge shapes shown in Figure 7, an appropriate value for W_L is 10^6 lbs.

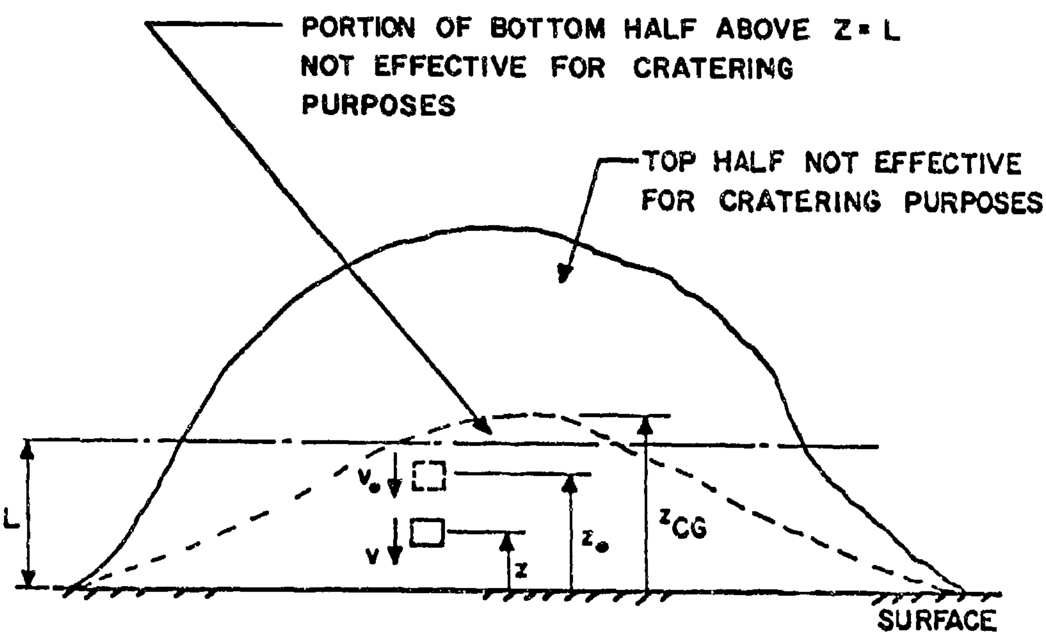


Figure 6. Notation for Typical Charge Shape

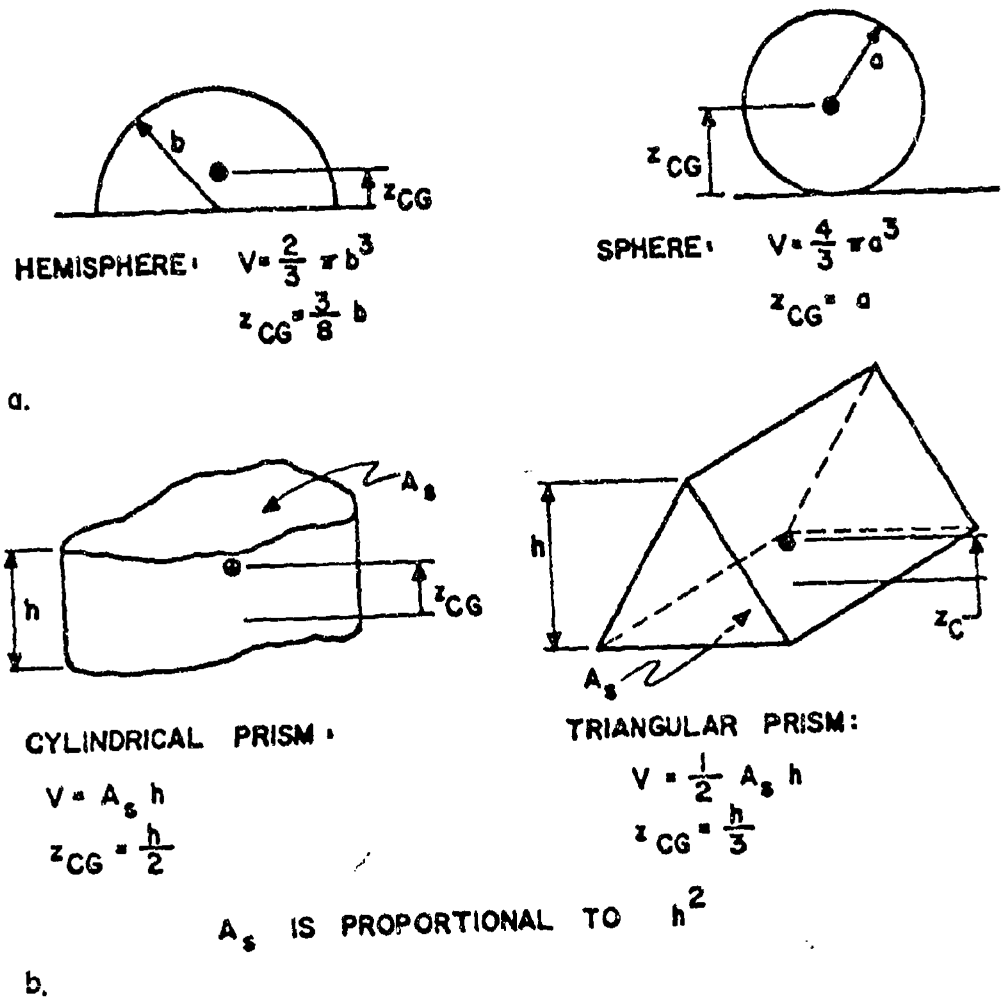


Figure 7. A Set of Four Charge Shapes

b. Crater and Ejecta Prediction

Parameters to describe the crater and ejecta shape for a cylindrical coordinate system placed on the original surface at the charge center are shown in Figure 8. The crater was assumed to be parabolic. For a crater of apparent depth D_a and apparent radius R_a, the slope at R = O was assumed to be zero. The shape of this crater could then be described by

$$x = D_a \left(1 - \frac{R^2}{R_a^{\ 2}}\right) \quad O \leq R \leq R_a \tag{11}$$

Material displaced from the crater to the surrounding region as called ejecta. Depth of ejecta, H_e, as a function of radial distance, R, can be described by the following relation, which is derived from a similar expression in Reference 6 for nuclear detonations.

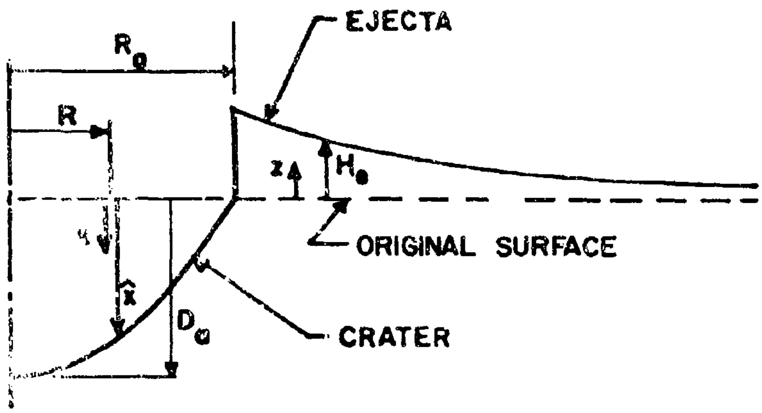


Figure 8. Idealized Crater and Ejecta Parameters

$$H_e = \frac{D_a}{4} \quad (\hat{\beta} - 2) \left\{ \frac{R_a}{R} \right\}^{\hat{\beta}} \tag{12}$$

Reference 6 suggests values of $\hat{\beta} = 3.9$ for soil and $\hat{\beta} = 3.1$ for rock. These values for $\hat{\beta}$, however, were found to yield results which did not compare favorably with available conventional explosion data. According, a value of 3.1 was chosen for $\hat{\beta}$ for soil in this study.

Material forming the ejecta was assumed to have been displaced in a radial direction from the crater. Coordinates of the radial crater element (pie section) centroid and the centroid of the corresponding ejecta element were determined by integrating and equating the volumes of these elements. The assumed total kinetic energy of the ejecta was based on the minimum amount of kinetic energy required to move the volume of ejecta along a trajectory from the crater element centroid to the ejecta element centroid. The kinetic energy will be less than the total energy input to the ground because of heat dissipation. By defining E_s^D to be the ratio of the energy lost in the form of heat to the total energy delivered to the soil for the reference charge, and by postulating that the ratio of D_a/R_a depends on

- earth media,
- mass density of earth medium,
- kinetic energy input to the soil, and the
- apparent crater radius R_a,

a relationship was developed using the theory of similitude. The resulting nondimensional equations are

$$\left(\frac{R_a}{R_a^o}\right)^{4+\zeta} = \frac{K^{1+\zeta}\left[1 - E_s^D\left(\frac{R_a}{KR_a^o}\right)^{1/2}\right]}{\left[1 - E_s^D\right]} \tag{13}$$

$$\frac{D_a}{D_a^o} = \left[\frac{R_a}{R_a^o}\right]^{1+\zeta} \frac{1}{K^{\zeta}} \tag{14}$$

where the parameters ζ and E_s^D are experimental constants. With R_a^o, D_a^o, ζ, and E_s^D known for a reference charge, these two equations give the apparent radius and depth as a function of K and hence as a function of the yield of the explosion. Equation 12 can then be used to predict the ejecta depth as a function of R utilizing an appropriate value for $\hat{\beta}$.

5. EXAMPLE RESULTS

Computer programs based on the previous sections are reported in Reference 7. Typical example results from these programs are summarized below.

a. Blast Pressure

The "Big Papa" Phases I and II test configurations were used as input to the program. The bomb stack was 30 ft wide x 50 ft deep x 8.83 ft high. Considering case effects, the equivalent weight of bare TNT in this stack was 186,000 lbs. The barricade was 100 ft wide x 70 ft deep x 11 ft high and open on one long side.

Figure 8a shows computed results for the above rectangular barricaded bomb stack along with an average of all "Big Papa" Phase I and II air pressure data; an umbarricaded hemispherical bare charge of the same weight is also shown for comparative purposes. Figures 8b and 8c illustrate the effects of charge shape and the barricade as compared to a bare hemispherical charge. Computed pressure isobars for the configuration described above are shown in Figure 9.

b. Fragmentation

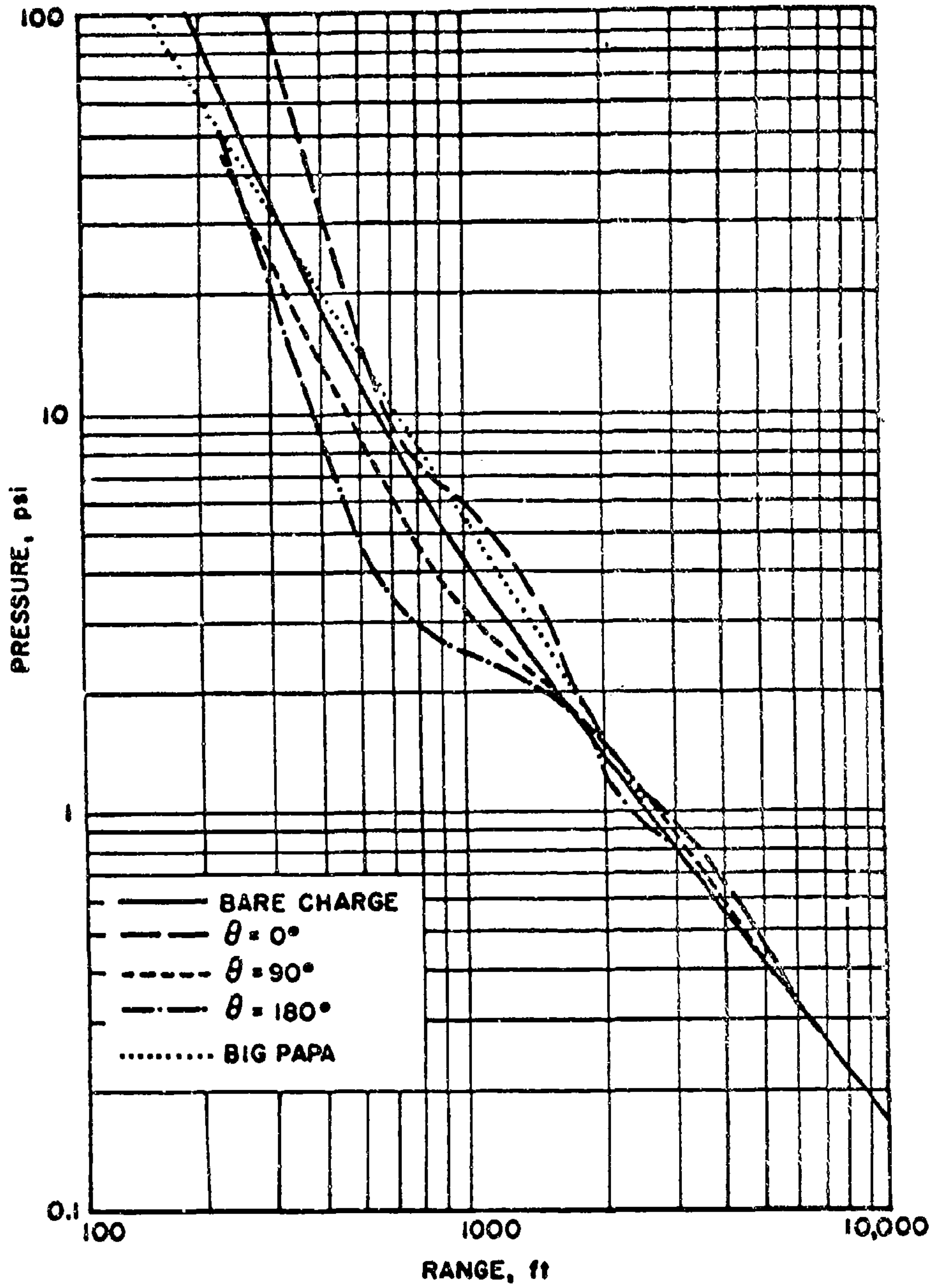
Fragment impact velocities and distribution were computed for the following hypothetical bomb stack.

- Stack and barricade geometry as described above for blast pressure.
- Each bomb had a gross weight of 1500 lbs.
- Each bomb contained 750 lb. of TNT.
- There were 333 bombs in the stack.
- The number of effective bombs considering the stack effect was 266.

Figure 10 shows the computed results out the rear of the barricade (θ=180°). The results of the analysis appear as piecewise lines of constant value because of the averaging techniques used by the computer program.

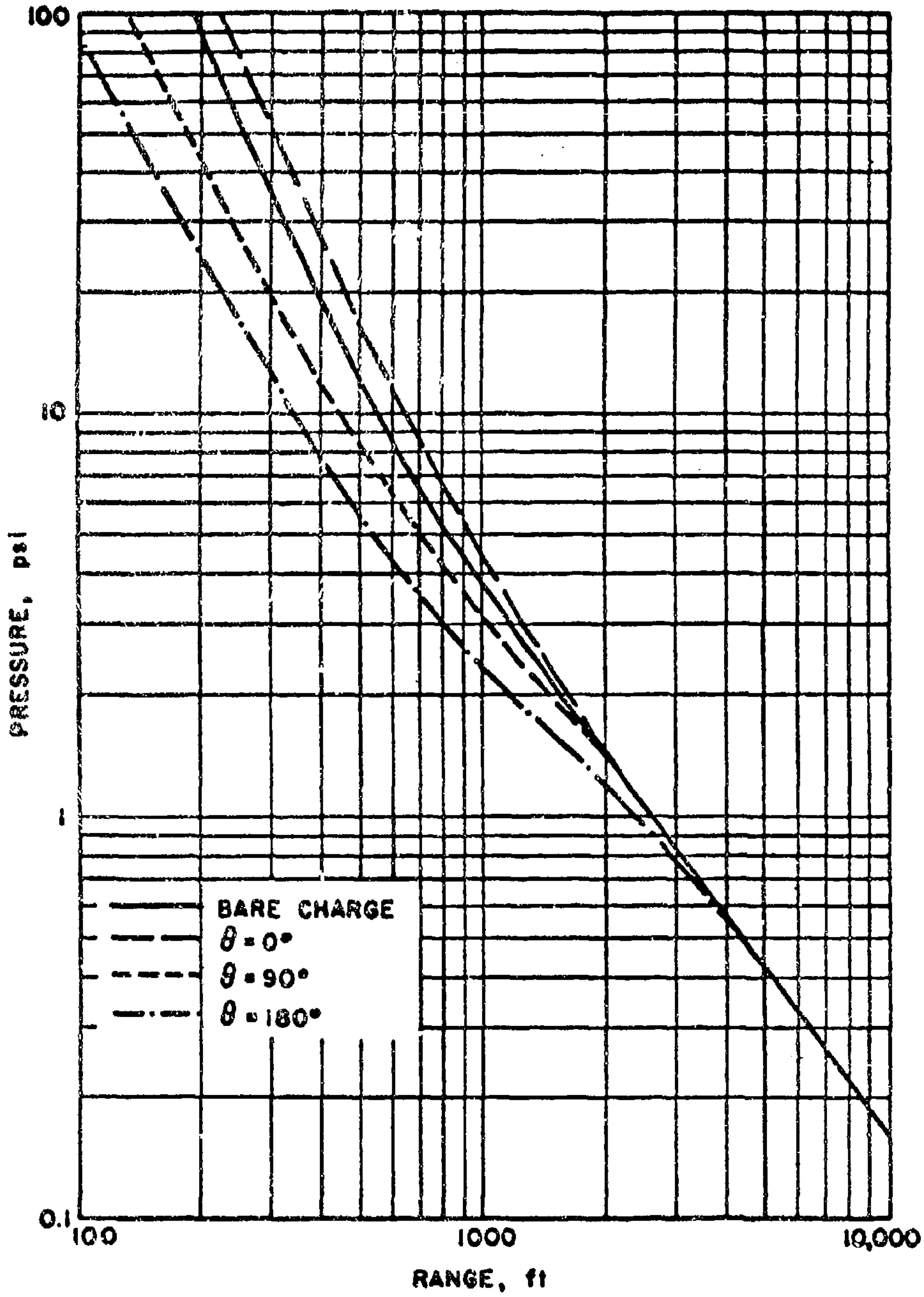
c. Crater and Ejecta Dimensions

The curves in Figure 11 show the computed apparent radius and depth of craters in soil for a range of 10 to 500 tons of TNT. It is evident from the figure that the 100 ton TNT hemispherical shot at Suffield Experimental Station was used as the reference charge. The following values were used in the calculations.



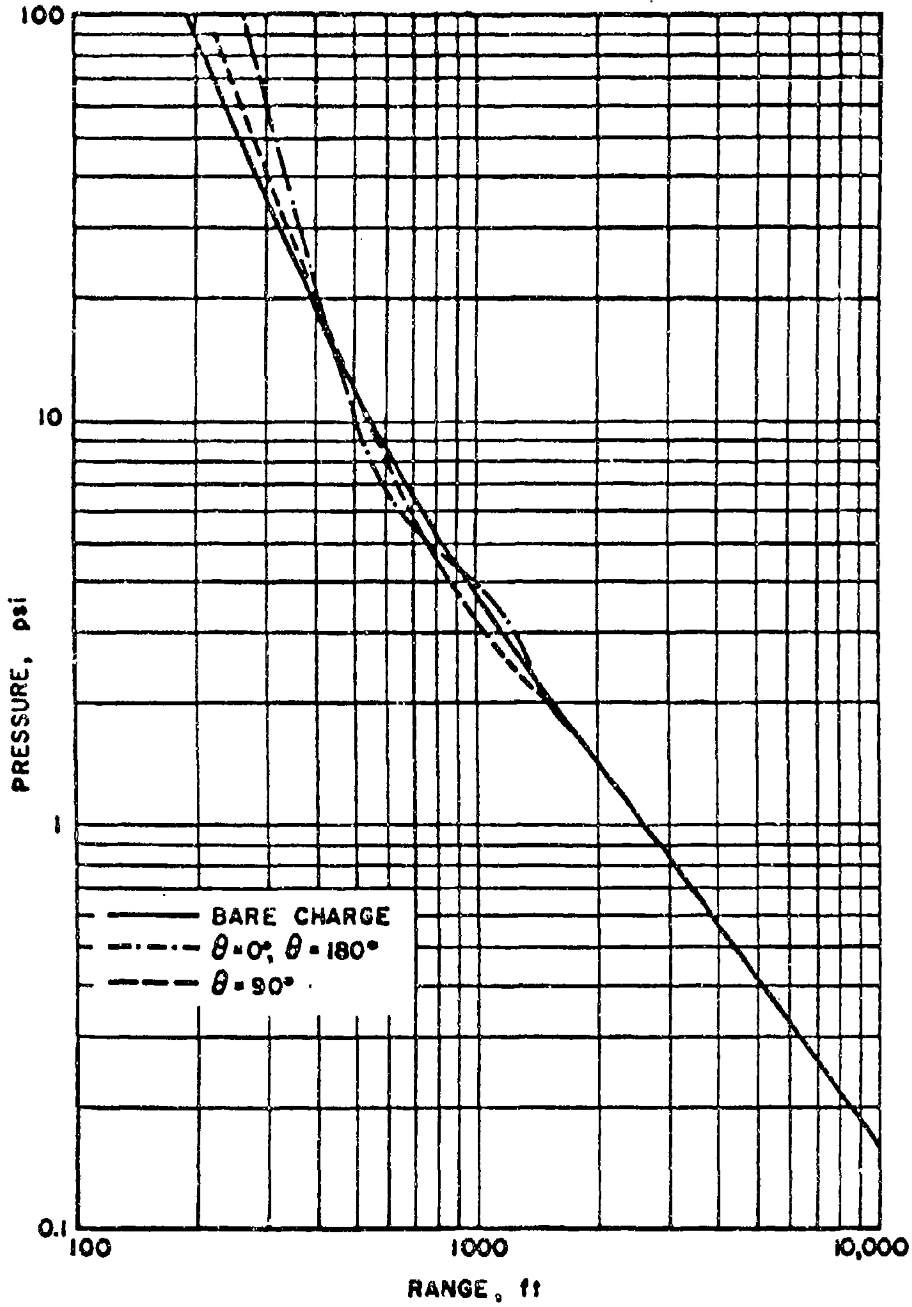
(a) Rectangular Barricaded and Hemispherical Unbarricaded (Bare) Charges

Figure 8. Pressure Versus Range for Various Charge and Barricade Combinations



(b) Hemispherical Barricaded and Unbarricaded (Bare) Charges

Figure 8. (continued)



(c) Rectangular and Hemispherical (bare) Unbarricaded Charges

Figure 8. (Continued)

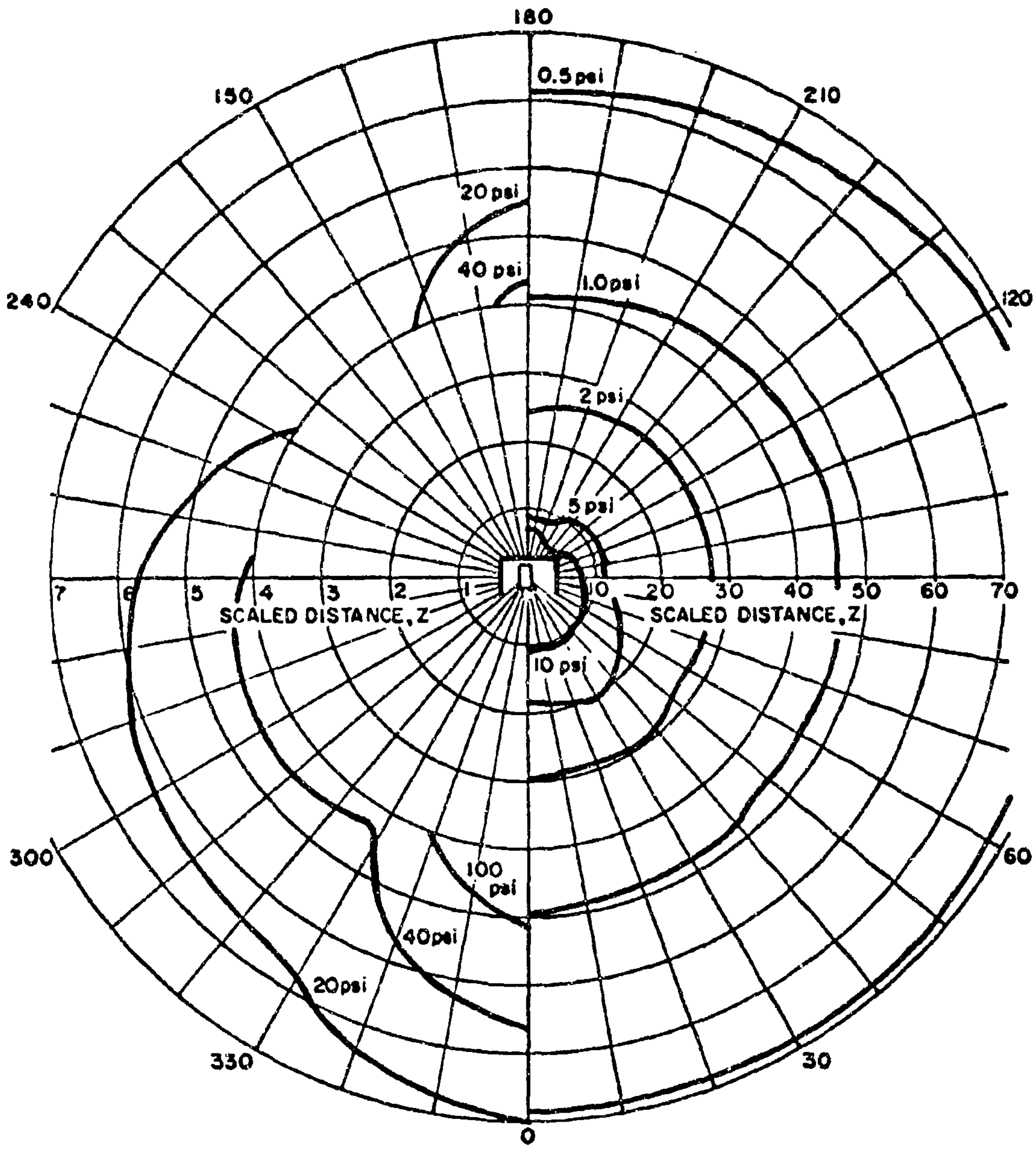


Figure 9. Pressure Isobars for a Rectangular Charge in a Three Sided Rectangular Barricade.

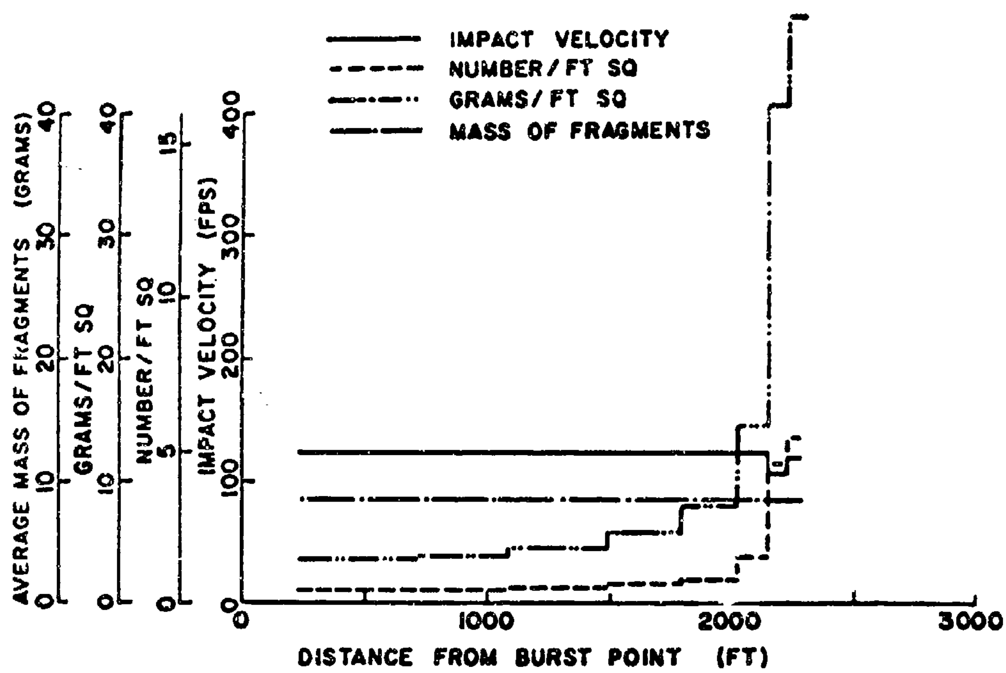


Figure 10. Impact Conditions vs Range for Fragments Ejected out the Rear of a Barricade

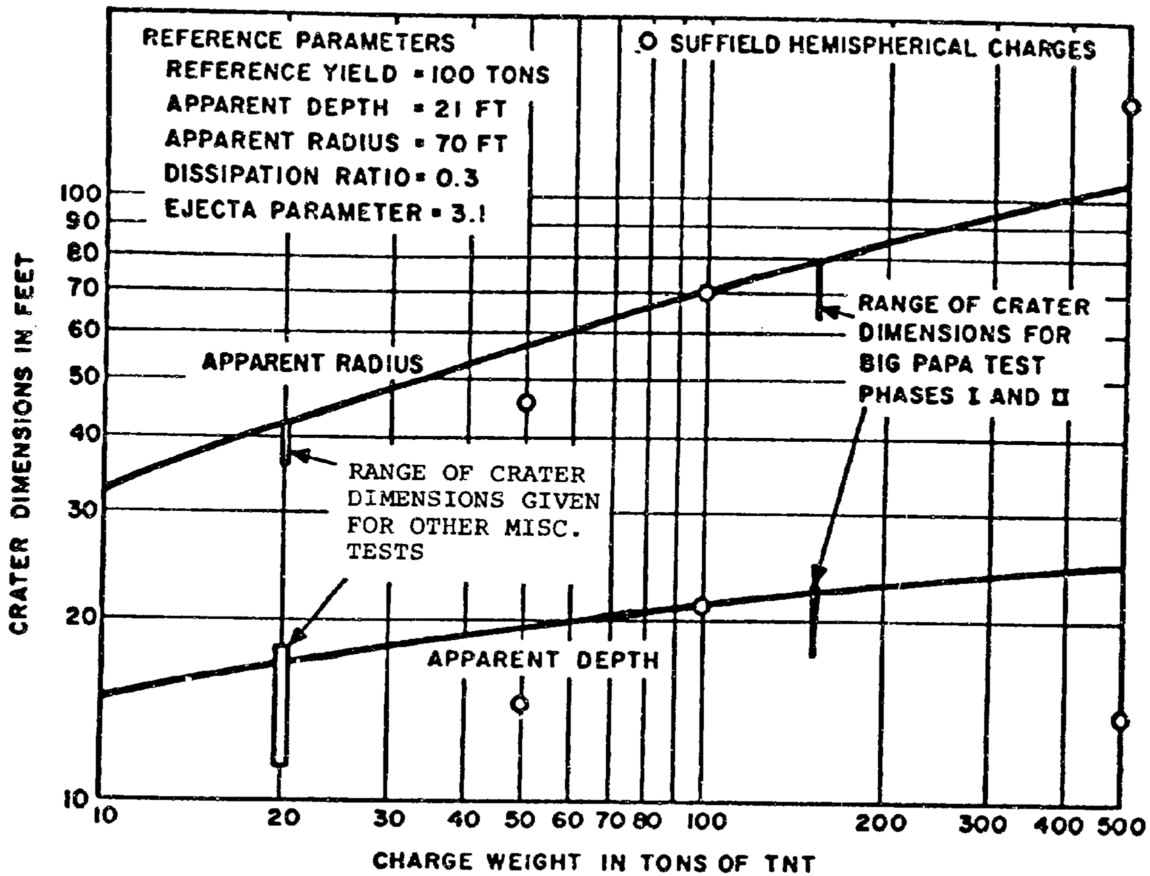


Figure 11. Apparent Crater Dimensions in Soil versus Charge Weight

- The dissipation ratio $E_s^D = 0.3$,
- ejecta parameter $\hat{\beta} = 3.1$, and
- $\zeta = 0.3$ for the range of charges considered.

The curves in Figure 11 show significant variation from scaling laws which would be represented by straightline relationships. Due to inclusion of basic principles of mechanics in development of the theory, the method should make it possible to predict crater dimensions on a more rational basis than the use of emperical scaling laws. For example, the parameters E_s^D and ζ can be changed if more data warrant such an adjustment. Also, the effect of charge shape can be treated.

The results shown in Figure 11 are strictly applicable only for the earth media associated with the reference shot where the soil, a silty clay, had a weight density of 94 lb/ft^3. Results from shots that may have been in a slightly different soil are also included in the figure for comparative purposes.

Predicted ejecta depths are shown in Figure 12 where the ejecta depth to apparent crater depth ratio is plotted as a function of the ratio of distance from the crater center (at the surface) to the apparent radius for various values of the ejecta parameter $\hat{\beta}$.

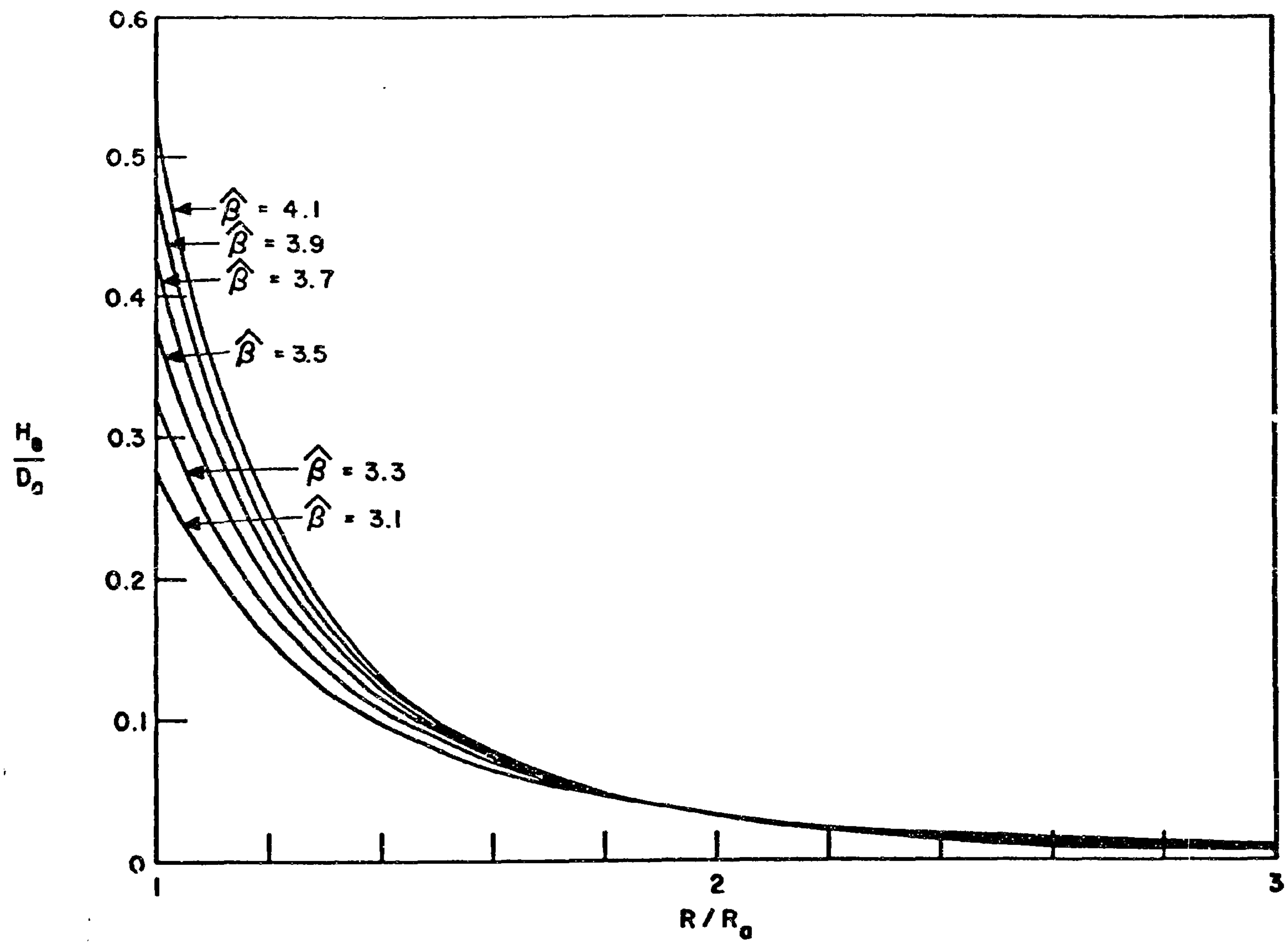


Figure 12. Non-dimensional Ejecta Shapes as a Function of Earth Media Parameter $\hat{\beta}$

REFERENCES

1. Manual for Design of Protective Structures Used in Explosive Processing and Storage Facilities, Tehcnical Report 3808, Picatinny Arsenal, Dover, New Jersey, November 1968.

2. Baker, W. E.; Grubbs, B. R.; Fitzgibbon, D. P.; (U) Non-Nuclear Weapons Effects on Protective Structures, Technical Report No. AFWL-TR-69-57, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, September 1969. (SECRET)

3. Adams, C. L.; Sarmousakis, J. N.; Sperrazza, J.; Comparison of the Blast from Explosive Charges of Different Shapes, Report No. 681, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, January 1949.

4. Cooper, C. A.; (U) Preliminary Warhead Terminal Ballistic Handbook, Part II - Warhead Terminal Ballistic Performance, NWL Report No. 1821, 15 August 1962.

5. Johnson, C.; and Smith, S. V.; Non-Nuclear Warhead Terminal Ballistic Handbook, Part II - Warhead Terminal Ballistic Performance, NWL Report No. 1864, U. S. Naval Weapons Laboratory, Dahlgren, Virginia, July 1964. (CONFIDENTIAL)

6. Effects of Air Blast, Ground Shock, and Cratering on Hardened Structures, AFSCM 500-8, Air Force Systems Command Manual, Headquarters, Air Force Systems Command, Andrews Air Force Base, Washington, D. C. 20331, 1 March 1967.

7. Schreyer, H. L.; and Romesberg, L. E.; Analytical Model for High Explosive Munitions Storage, Technical Report No. AFWL-TR-70-20, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, June 1970.

8. Peterson, F. H.; Lemont, C. J.; Vergnolle, R. R.; High Explosive Storage Test - Big Papa, Technical Report No. AFWL-TR-67-132, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, May 1968.

9. Explosive Hazard of Rocket Launchings, Technical Report No. U-108:98, Aeronutronic Division of Ford Motor Company, November 30, 1960.

"COMPARTMENTED STORAGE STRUCTURES"

by

A. J. Palfey
The Dow Chemical Company
Midland, Michigan 48640

PRECEEDING PAGE BLANK

ABSTRACT

The Dow Chemical Company of Midland, Michigan, under a Defense Nuclear Agency Contract, (formerly The Defense Atomic Support Agency DASA), has developed a sand containment system to replace the sand bag dividing walls currently used in compartmented storage structures. Protection is required for high explosive storage against the propagation modes of fragment initiation, over pressure crushing and translation. Compartments are constructed by abutting short wing walls perpendicular to either one or two sides of a long main wall. The walls of sand measuring 22 inches wide and up to 96 inches in height are contained between two walls of lightweight extruded polystyrene foam boards. All materials of construction are lightweight having virtually no potential for generating undesirable secondary fragments. The system is designed for shipment of a complete prefabricated unit to a storage site ready for field assembly with minimum hand tools, instructions or technical supervision. Cost is comparable to conventional sand bag systems and expected life is over 10 years. Reliability of performance is based on over 9 months laboratory testing of full scale sand filled wall sections.

ACKNOWLEDGMENT

The author wishes to acknowledge the assistance of the Defense Nuclear Agency representatives LTC W. D. Nelson, USA and Mr. Charles J. Haney, who established the requirements for this project and gave valuable direction with their broad knowledge in munitions storage.

In addition the author wishes to acknowledge The Dow Chemical Company personnel, Mr. V. L. Hannaford and Mr. W. P. Hovey for their aid in the investigation, development and testing of the barrier system along with the project management assistance furnished by H. S. Smith and B. A. Russell.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (con't.)

1. INTRODUCTION

1.1 Earth Covered Magazines

In recent years, steel and reinforced concrete arch type magazines have been approved and standardized by various government agencies for storage of modern weapons and explosives. These magazines afford advantages by providing protective storage more quickly and more economically on less land than other types of storages.

Typical earth covered magazines, sketched on Figure 1 and Figure 2, are not designed to resist damaging effects of its explosive contents, but primarily to prevent propagation of an accidental explosion.

This document is concerned with the protective structure that is the barrier system made up of compartments within earth covered magazines. The individual explosive storage compartments are designed to attenuate the donor output at tolerable levels to protect the receiver in event of accidental initiation. Protection must be provided against propagation modes of fragment initiation, over pressure crushing and translation.

1.2 Present Sand Bag Barriers

Protective barrier systems constructed of sand bags are very efficient when stacked in a prescribed manner. However, on long term storage the bags tend to settle or change position, or even fall to generate a hazardous condition. Thus, the problem is to develop an improved barrier system which combines the same protection as sand bags, but with long term storage capability having minimal maintenance and virtually no potential for secondary fragment production.

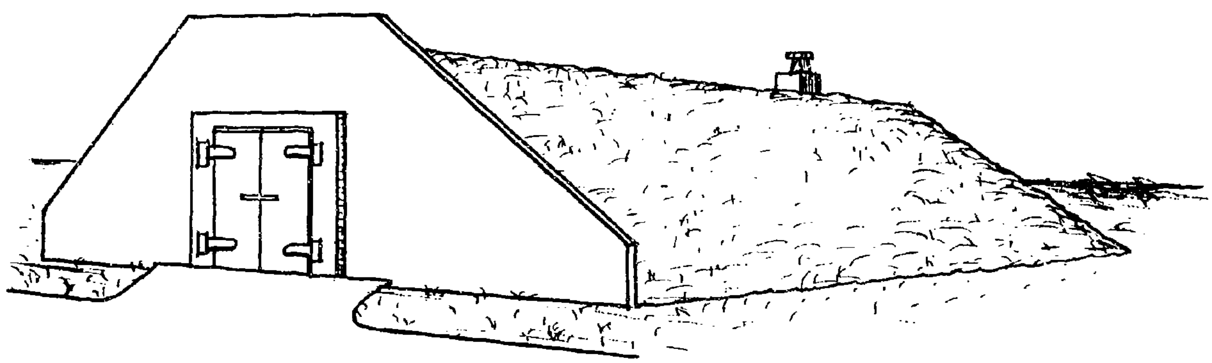


Fig. 1 Typical Earth-Covered Arch Type Magazine

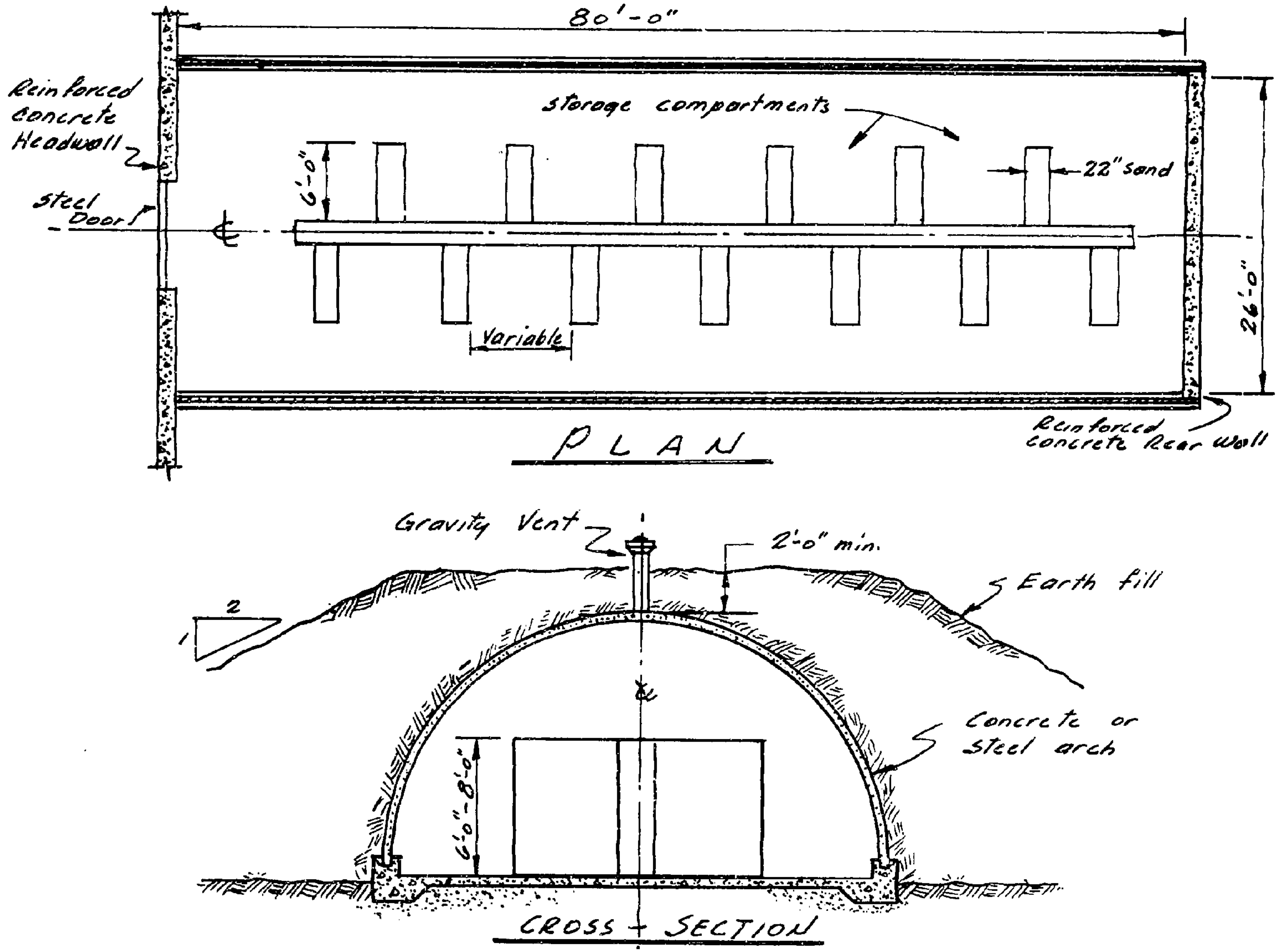


Fig. 2 Typical Earth-Covered Magazine Details

1.3 Contract Award

In October, 1970, the Defense Atomic Support Agency (DASA), presently the Defense Nuclear Agency (DNA), awarded The Dow Chemical Company, Midland, Michigan, a contract to conduct a research program with the objective of the selecting and developing an optimum protective barrier system for magazine munitions storage.

1.4 Compartmented Barrier Requirements

The significant requirements for the new barrier system as established by DASA respresentatives are;

- Contain a 22" thick wall of wet or dry sand of 1/8" maximum grain size.
- Have flexibility in establishing wall heights up to 8 ft. and altering compartment size.
- Wall and wall tie material to have virtually no potent[illegible] becoming hazardous secondary fragments.
- All raw materials should be commercially available and adaptable to fabrication, assembly, and maintenance simplicity.
- The system cost should be comparable to existing sand bag installations.
- Life expectancy of over 10 years.

2. MATERIAL SELECTION

2.1 Commercial Plastic Foams

Of all the lightweight structural materials considered, rigid plastic foam has the greatest potential of meeting the barrier wall requirements. Although plastic foams are noted for their thermal insulation properties, they are used extensively in such structural applications as load bearing sandwich panels, in Spiral Generated dome buildings and in structural marine applications. In addition, plastic foams resist rot and fungus and contain no food value to attract insects and rodents. Because of the materials moisture resistance and closed cell structure, they will not significantly deteriorate upon long-term exposure to moisture.

The most widely used structural plastic foam materials are:

Foam Type	Available Form
. Extruded polystyrene STYROFOAM® brand plastic foam	Boards and billets
. Expanded polystyrene beads	Molded shapes, boards, and billets
. Urethane	Molded shapes, boards and billets

The photos, Figures 3,4,5,and 6 with six X magnification, shows the cell structure of the three basic foam types.

2.2 Plastic Foam Properties

The significant structural properties of the three basic foam types and their relative costs are tabulated on Figure 7 Although any of these foam types are applicable to a barrier wall design, the most economical and structurally strongest foam for equivalent weight and volume is extruded polystyrene foam.

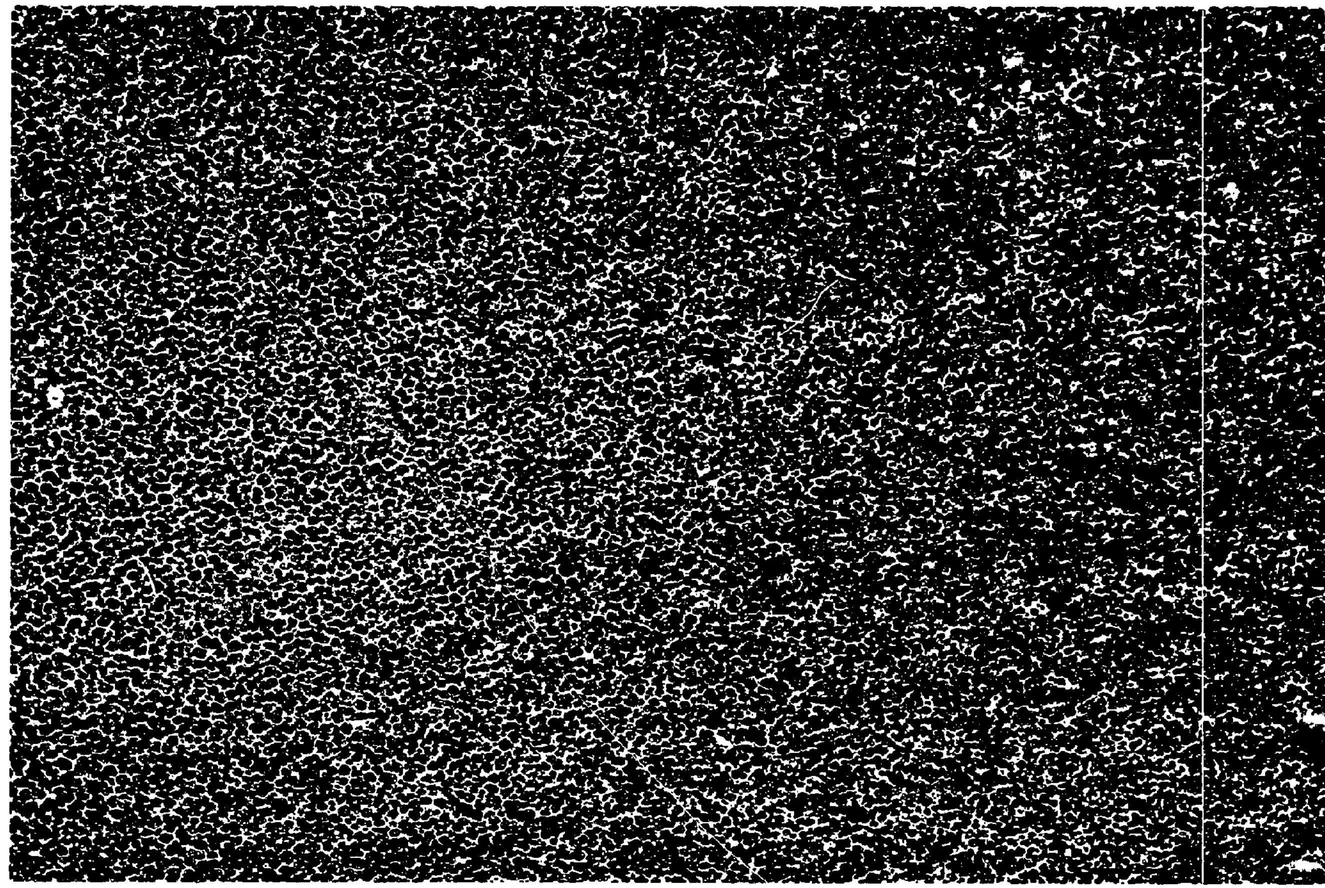


Fig. 3 Extruded Polystyrene Foam
STYROFOAM Brand Plastic Foam
2 lb/cu ft density

Fig. 4 Extruded Polystyrene Foam
STYROFOAM Brand Plastic Foam
3.2 lb/cu ft density

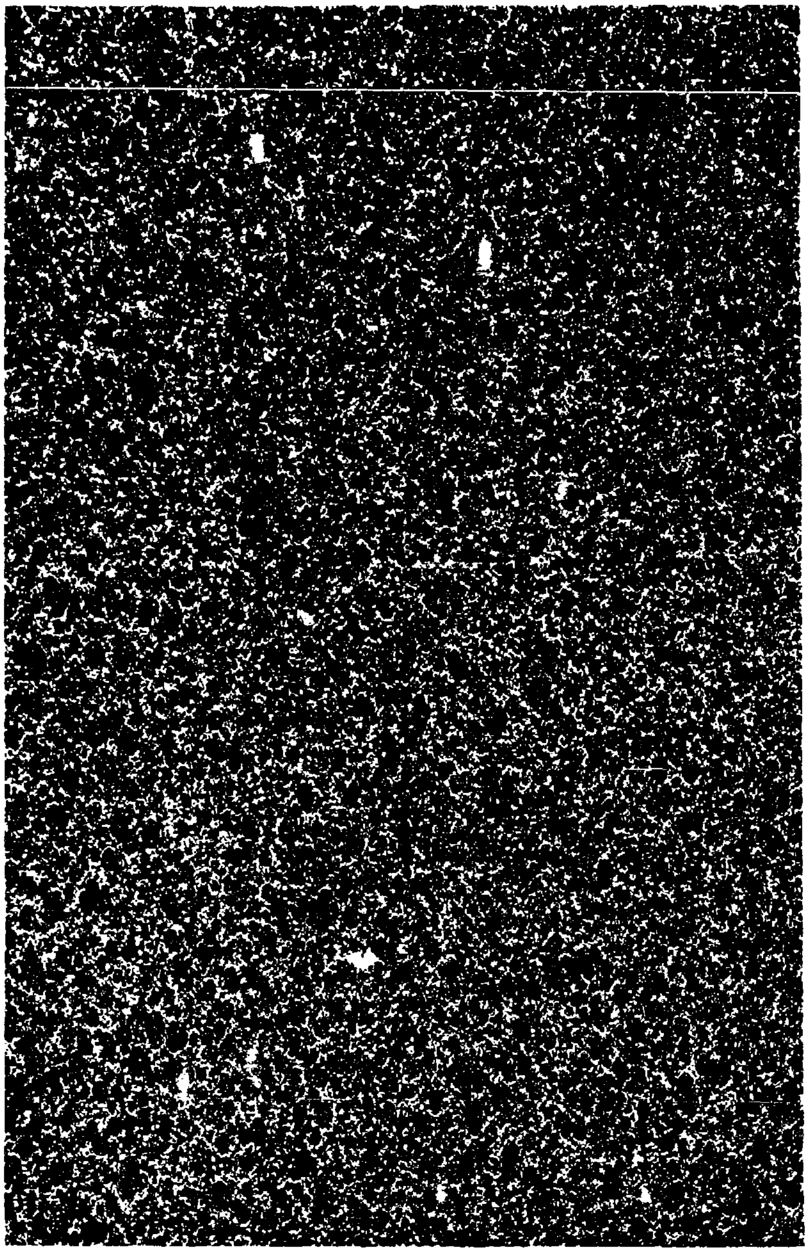


Fig. 5 Urethane Foam
2 lb/cu ft density

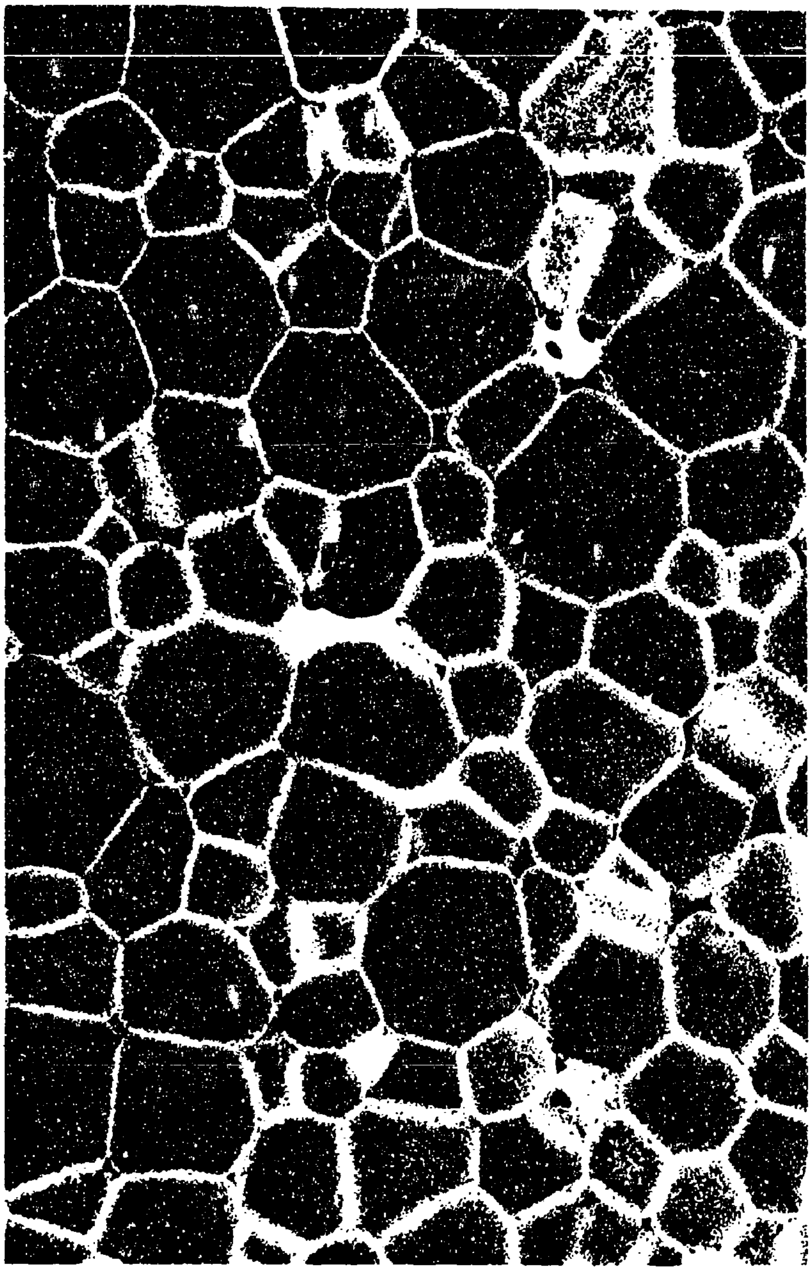


Fig. 6 Expanded Polystyrene Bead Foam
1.2 lb/cu ft density

Type	Form	Density lbs./cu.ft.	Flexural Stress psi	Flexural Modulus psi	Compressive Strength psi	Cost Bd/Ft $
ASTM Test			C-203	C-203	D-1621	
Extruded Polystyrene	Boards, Logs	1.8	60	1800	30	.10
	Boards, Logs	3-4.5	90-135	2300-4600	125-175	.23
Expanded Polystyrene Beads	Boards, Panels, Molded Shapes	1-2.0	28	1100-1500	8-12	.08
Urethane	Boards, Panels, Molded S.	1.9	45	1500	25	.15
	Boards, Panels, Molded S.	4.1	90	2000	80	.50

Fig. 7 - Plastic Foam Properties

3. DESIGN

3.1 Basic Concepts

Various wall concepts were evaluated utilizing commercial plastic foams in the form of boards and molded box and block shapes. The system better qualified to meet the basic requirements was a wall system constructed of foam boards stacked in courses with splined butt and corner joints. Using the basic spline joining system sketched on Figure 8, the main center wall and separate wing walls are made into box type structures to contain sand and to form storage compartments shown on Figure 9. Wall to wall ties are required to retain the lateral wall pressure developed by the sand.

3.2 Wall Loads

Lateral wall pressure developed by a head of sand is the most significant design consideration. This pressure must be sustained by the foam wall and wall ties without excessive deflection, or excessive tensile and flexural stresses for a period of over 10 years. In a literature survey the magnitude of these forces was found to range from 40% to 50% of the vertical sand load, noted as a lateral wall pressure coefficient (k) ranging from 0.4 to 0.5.

4. WALL PRESSURE TESTING

4.1 Panel Wall Model

Since most of the empirical coefficients are based on small laboratory scale models of different configurations, it was decided to build a full scale wall model 22" wide x 96" long x 96" high and measure the wall pressure. The test

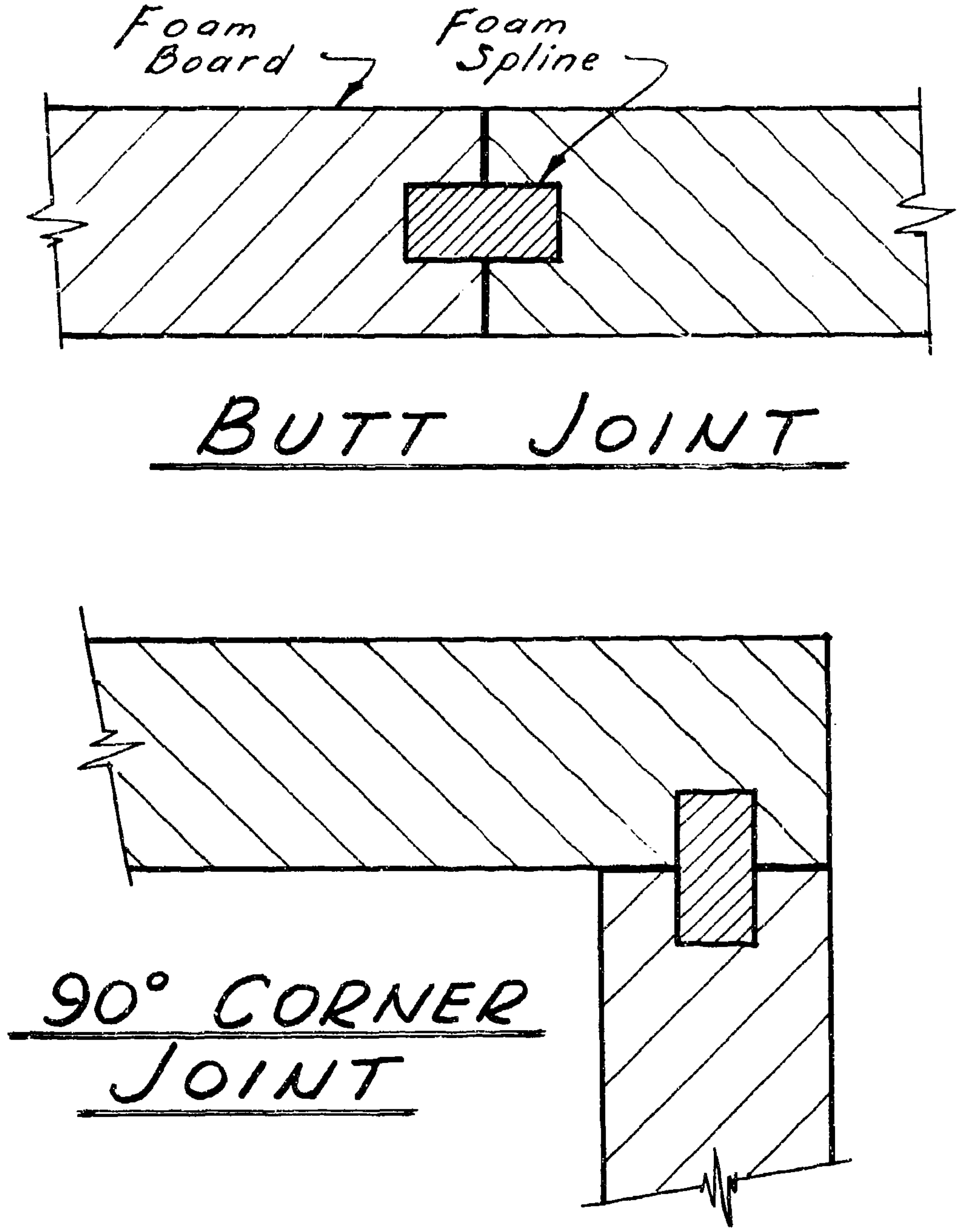


Fig. 8 Spline Joint Details

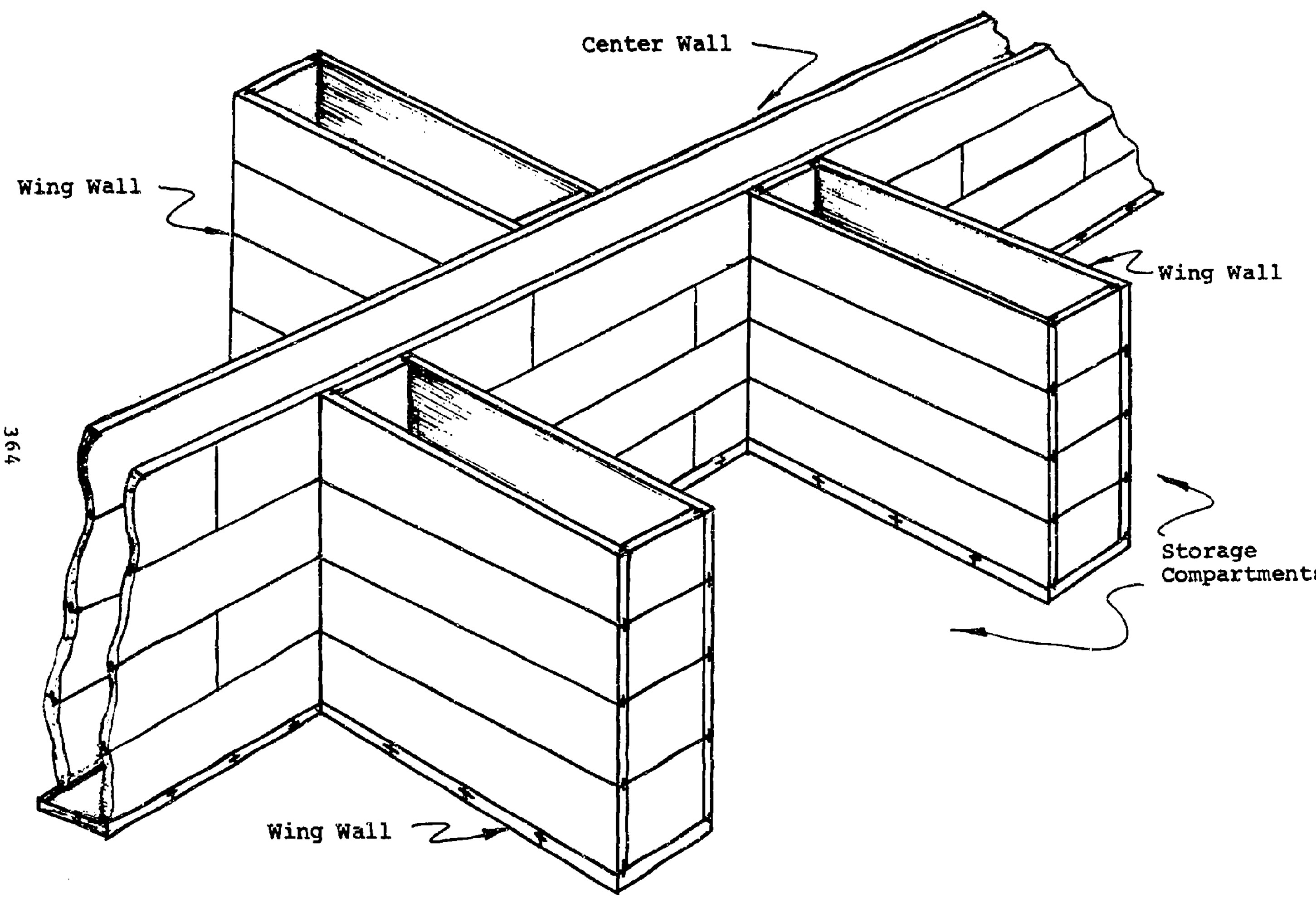


Fig. 9 Foam Board Compartment Assembly

box wall was constructed of structural aluminum faced sandwich panels. Kiln dried Lake Michigan beach sand was used to develop maximum wall pressure. The measured pressures, plotted on Figure 10, are equivalent to a lateral coefficient of 0.4 initially, but then pressure drops off exponentially with increased sand head. The maximum pressure measured for an 8 ft. high wall was 0.85 psi.

4.2 Foam Wall Model

Since the measured wall pressures were relatively low it was decided to continue wall testing using high density foam boards for the structure. Calculations were made to determine the wall thickness required for a wall tied on a 16" x 16" grid, using the equations on Figure 11. The simple beam theory was used rather than Timoshenko's plate theory because it is simplier to apply and about 15% more conservative.

The flexural stress developed in a loaded wall will normally determine wall thickness. Using the highest strength extruded polystyrene foam and limiting flexural stress to 30 psi for short term loading, the calculated wall thickness required was 2".

A test wall was fabricated from standard 16" wide x 108" long boards with conventional wood working tools. Splines and spline grooves were cut on a table saw at wood cutting speeds.

The photo, Figure 12, shows the test wall 22" wide x 96" long being loaded with sand. Rigid wall ties were used to limit wall movement at those points and to provide for a dynamometer attachment to one free end. The dynamometer

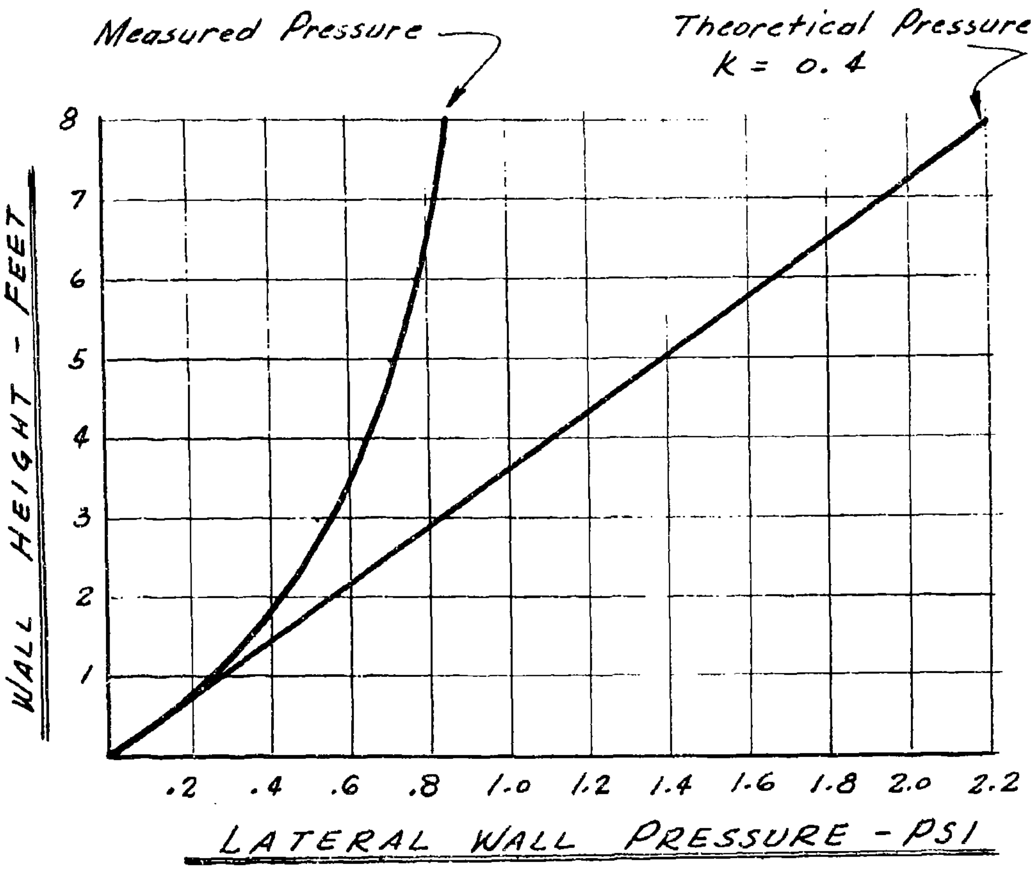
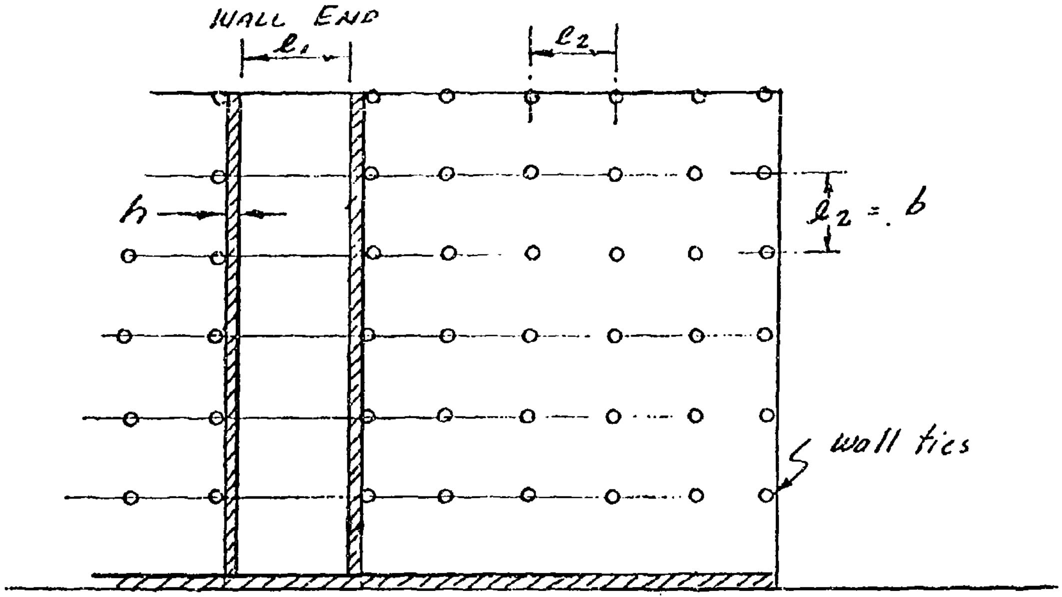
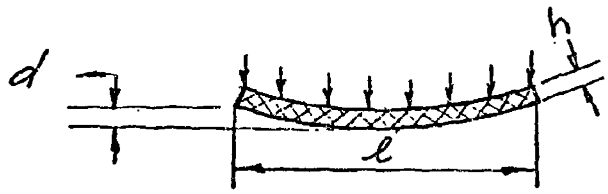


Fig. 10 Measured Lateral Wall Pressures





$$C = \frac{h}{2}$$

● deflection, $d = \dfrac{5wl^4}{384EI}$, $I = \dfrac{bh^3}{12}$

E = Flexural Modulus

Max. Fiber Stress, $S = \dfrac{Mc}{I}$ $M = \dfrac{wl^2}{8}$

For square ties $S = \dfrac{3wl}{4h^2}$

● Calculated as a simple beam. For more accurate calculations refer to Timoshenko's "Theory of Plates and Shells" pp. 218 - 220

Fig. 11 - Wall Strength Calculations

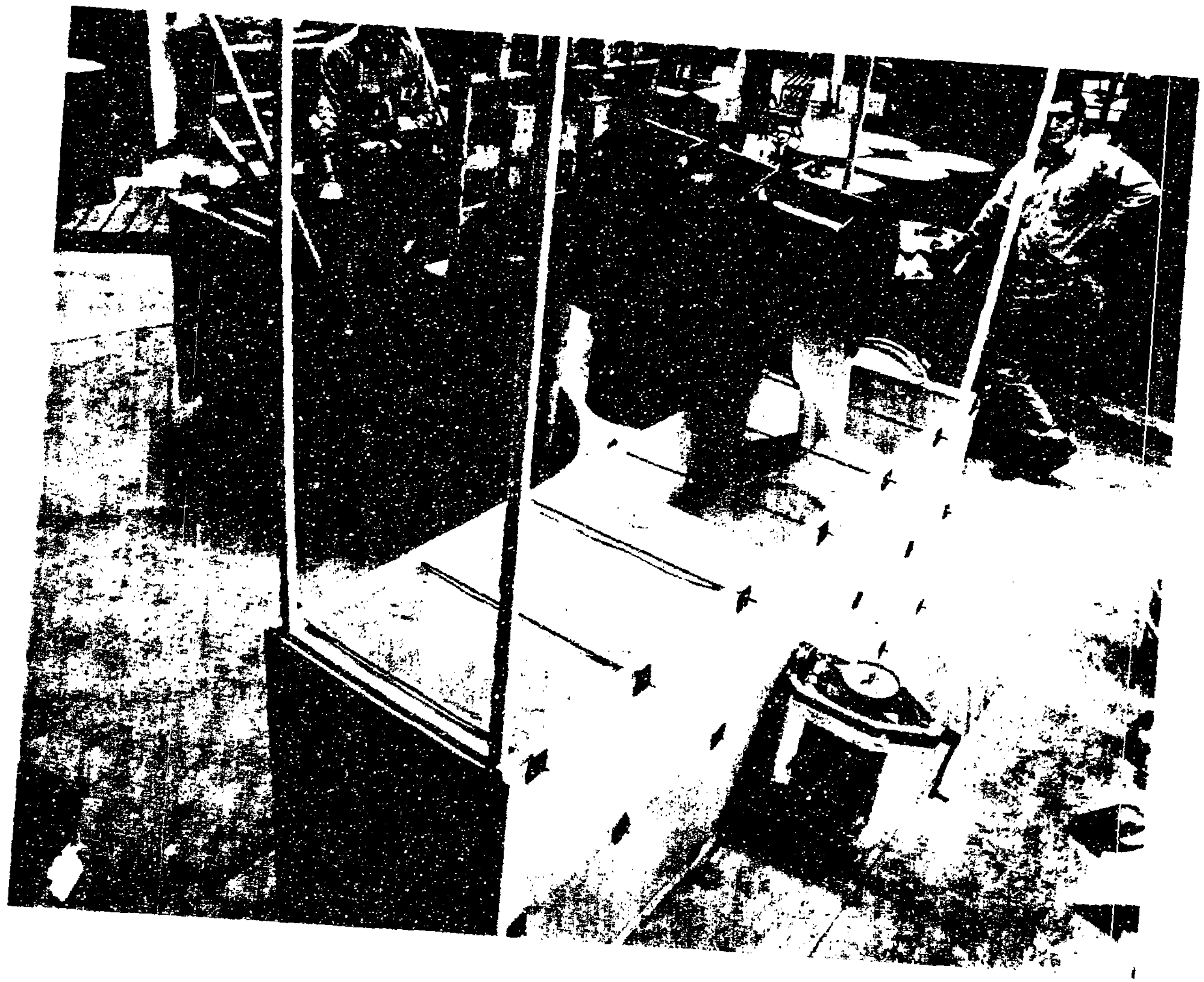


Fig. 12 Loading Sand in Test Wall

measures the lateral wall load over a 16" x 16" area, which is also the wall tie restraining load. A completely assembled and sand filled wall 8 ft. high is shown on Figure 13.

The measured wall pressures are plotted on Figure 14. The maximum dynamometer load was 166 lbs. or equivalent to 0.65 psi and less than 0.85 psi measured on the panel wall model. This difference is attributed to the difference in sand/wall friction of the two materials.

The extent of wall friction and sand loads was measured at various sand heights. The plot on Figure 15 shows that the total weight of sand is 1460 lbs. per ft of wall and that 800 lbs. per ft. of wall is carried by the foam walls due to wall friction. Therefore, lateral wall pressure is developed by the remaining vertical sand load of 660 lbs. which accounts for the lower than expected wall pressure.

5. CREEP CHARACTERISTICS

Wall deflection measurements were made on a loaded wall over a period of time to determine the foam wall creep characteristics. The change in wall deflection reached equilibrium conditions after 60 days. This was a much shorter time than expected and indicated the sand lateral pressure decreased during this test period.

The time/lateral pressure characteristics of sand was measured on a Jenike-Johanson, Inc. Flow Tester. Results of the change or increase in the internal angle of friction of sand under pressure for 21 days is plotted on Figure 16. This plot shows the angle of friction increases and equivalent lateral pressure decreases with time, and confirms wall creep reaching equilibrium conditions after 60 days.

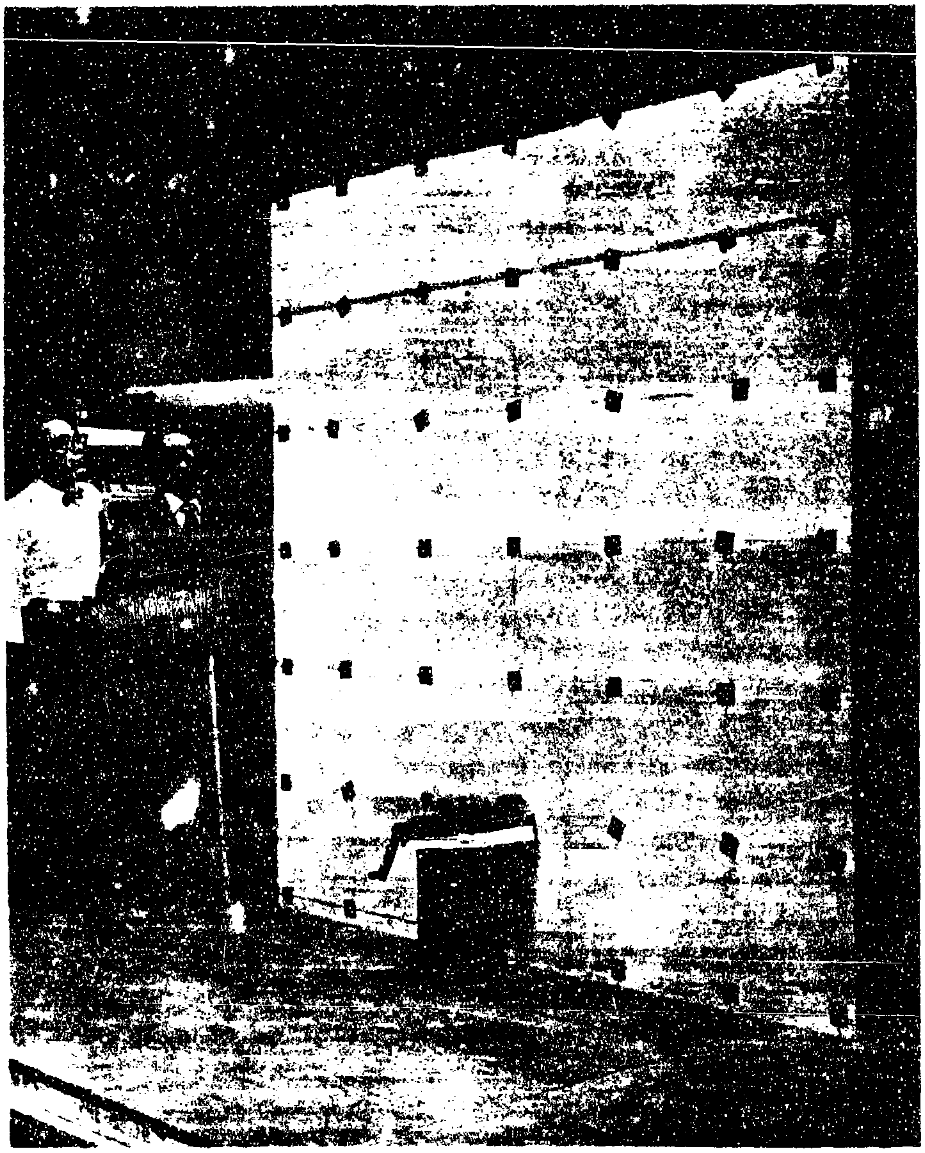
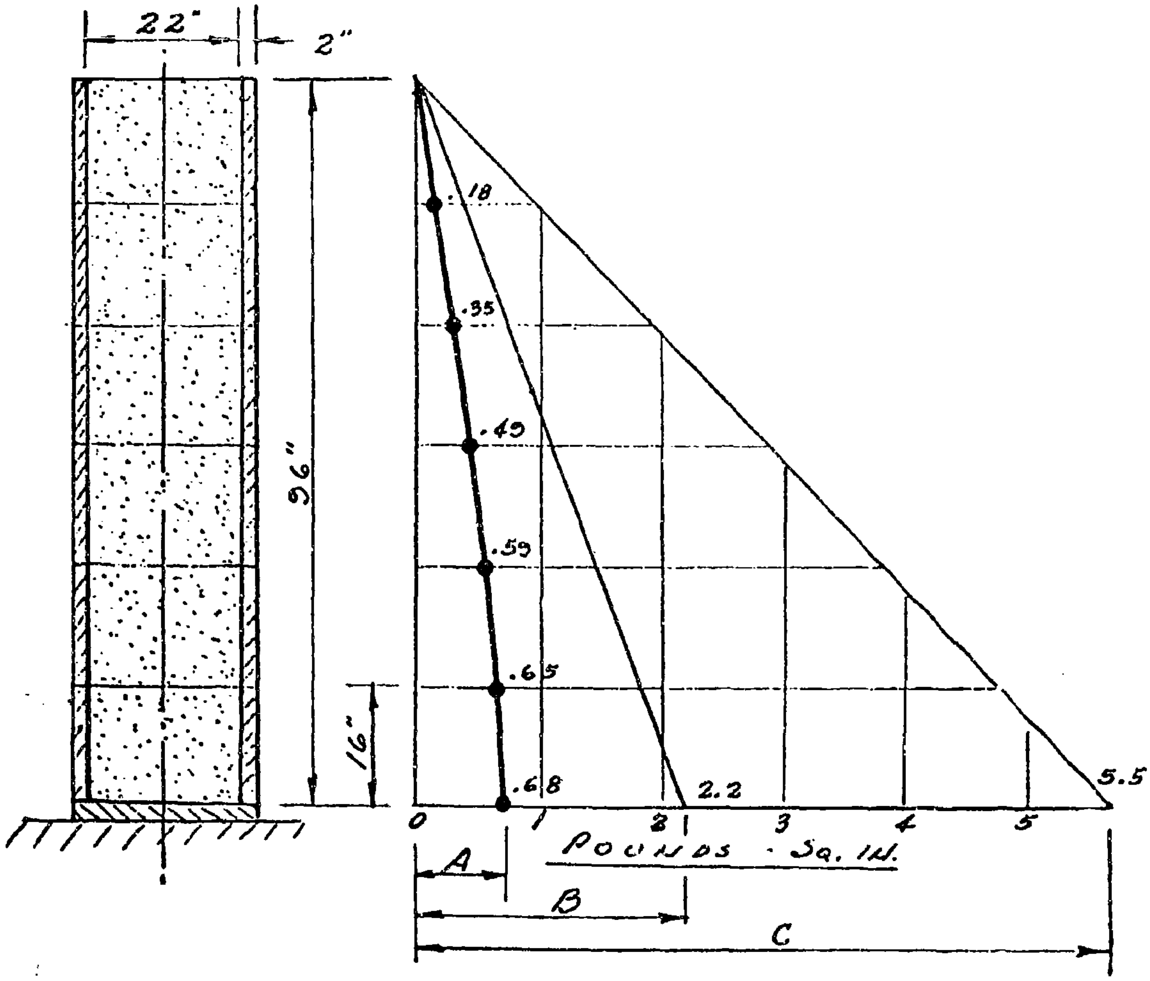


Fig. 13 Sand Filled Test Wall



A = Measured lateral wall pressure.

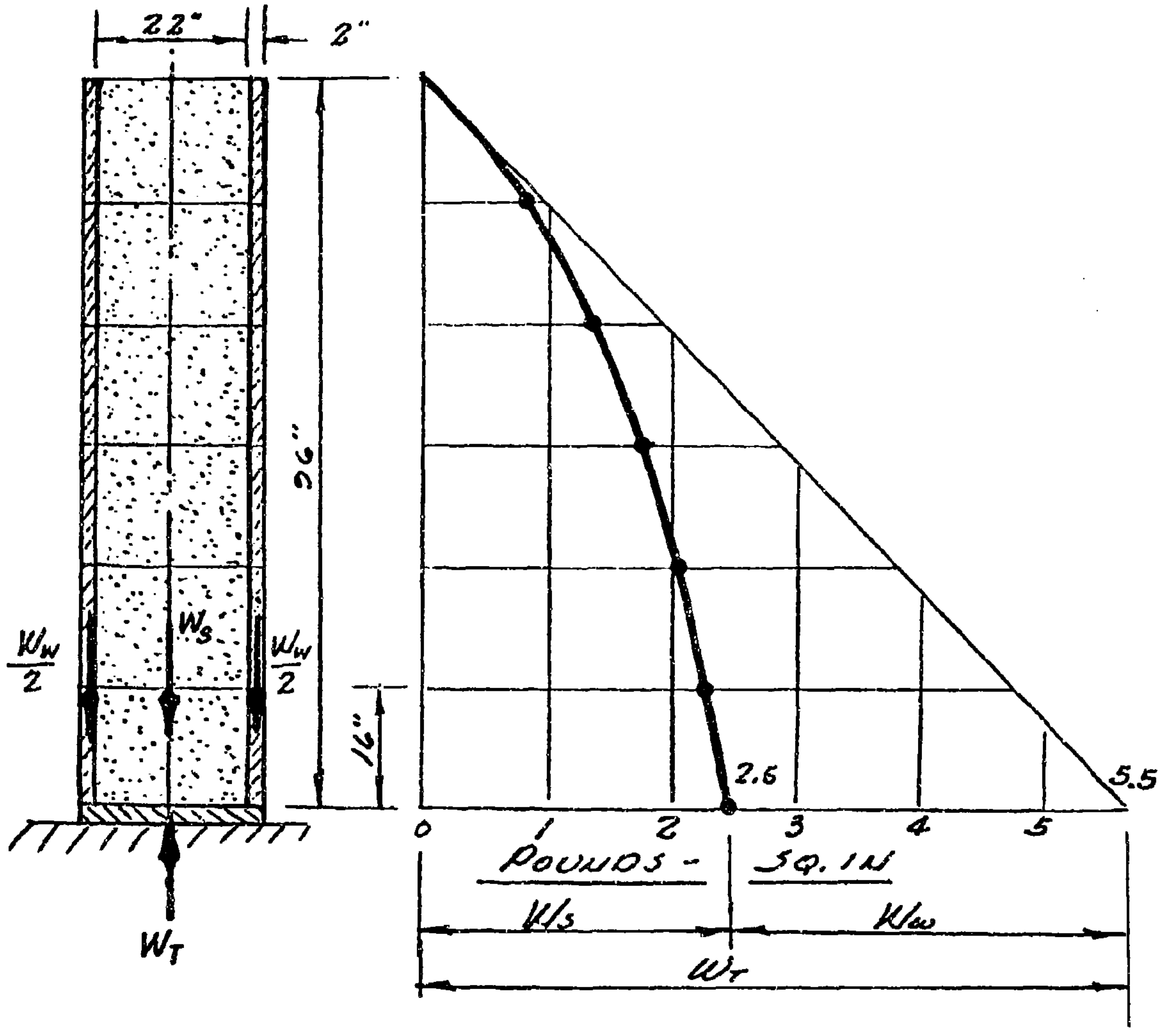
C = Theoretical sand pressure on the supporting base without sidewall friction.

$$C = \frac{(8 \text{ ft.})(100\ \#/\text{ft}^3)}{144} = 5.5 \text{ psi}$$

B = Theoretical lateral wall pressure with k = 0.4

$$B = kC = (0.4)(5.5) = 2.2 \text{ psi}$$

Fig.14 - Measured Lateral Wall Pressure



W_s = Sand pressure measured on base

W_s = (2.5 psi) (22" x 12") = 660 lbs./ft.

W_T = Total weight of sand

W_T = (5.5 psi) (22" x 12") = 1460 lbs./ft.

W_w = W_T - W_s = 1460 - 660

W_w = 800 lbs.

Fig.15 - Vertical Sand And Wall Loads

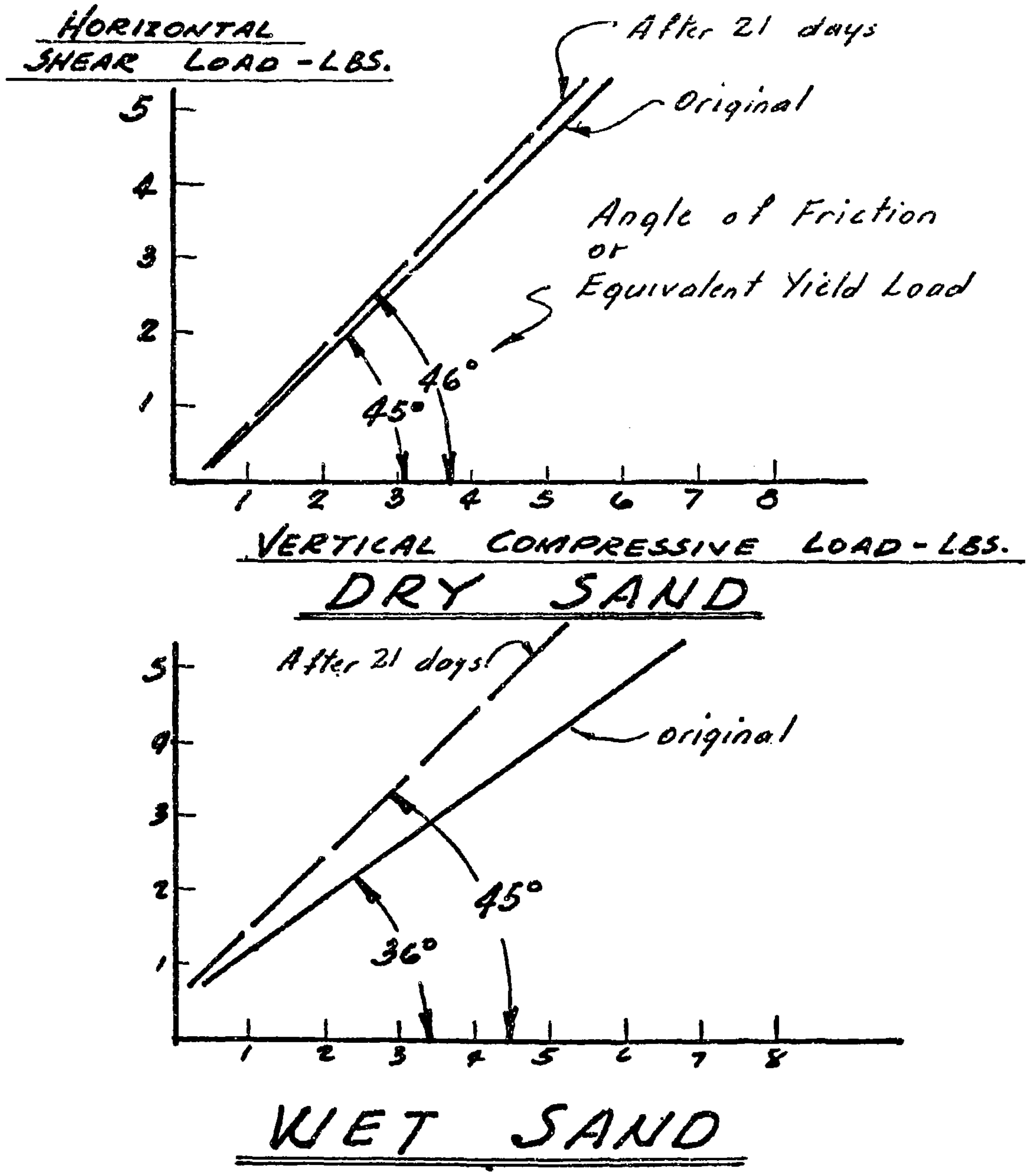


Fig. 16 - Change of Wet and Dry Sand Angle of Friction Versus Time (Measured with Jenike-Johanson Inc. Flow Factor Tester)

6. WALL TIES

The wall tieing system selected consists of 1" nylon webbing sewn into endless bands. Walls are tied by inserting the webbing into vertical saw cuts spaced on 16" centers on the horizontal joints, below the splines, as shown on Figure 17. The maximum webbing tension on a loaded 8 ft. high wall is 83 lbs. The webbing selected complies with MIL-T-5038, Type IV. After sewing,the breaking strength is 500 lbs, for a design safety factor of 6.

7. PROTOTYPE COMPARTMENTED STRUCTURE

A prototype compartmented structure 8 ft. high and 27 ft. long was designed and assembled at the Midland Laboratory. Walls 2" and 3" thick were loaded with kiln dried beach sand and wet mason sand. The photo Figure 18 shows a 1/2 yard mechanical loader filling a 2" wing wall with wet sand. Other photos Figures 19 and 20 shows various stages of the compartmented structures assembly.

8. GENERAL COMMENTS

Board walls 2" and 3" thick will assemble square and plumb without the aid of tools. Wall distortion may be developed while loading sand by exerting more force on one wall than the other. When this occurs a level should be used to maintain the wall plumb by hand positioning.

The spline system of joining boards retains fine dry sand without leakage.

Although wet sand was poured into the foam wall from a 6 ft. height without excessive vibration, it is recommended walls be assembled and filled in increments of 32", or two board course heights.

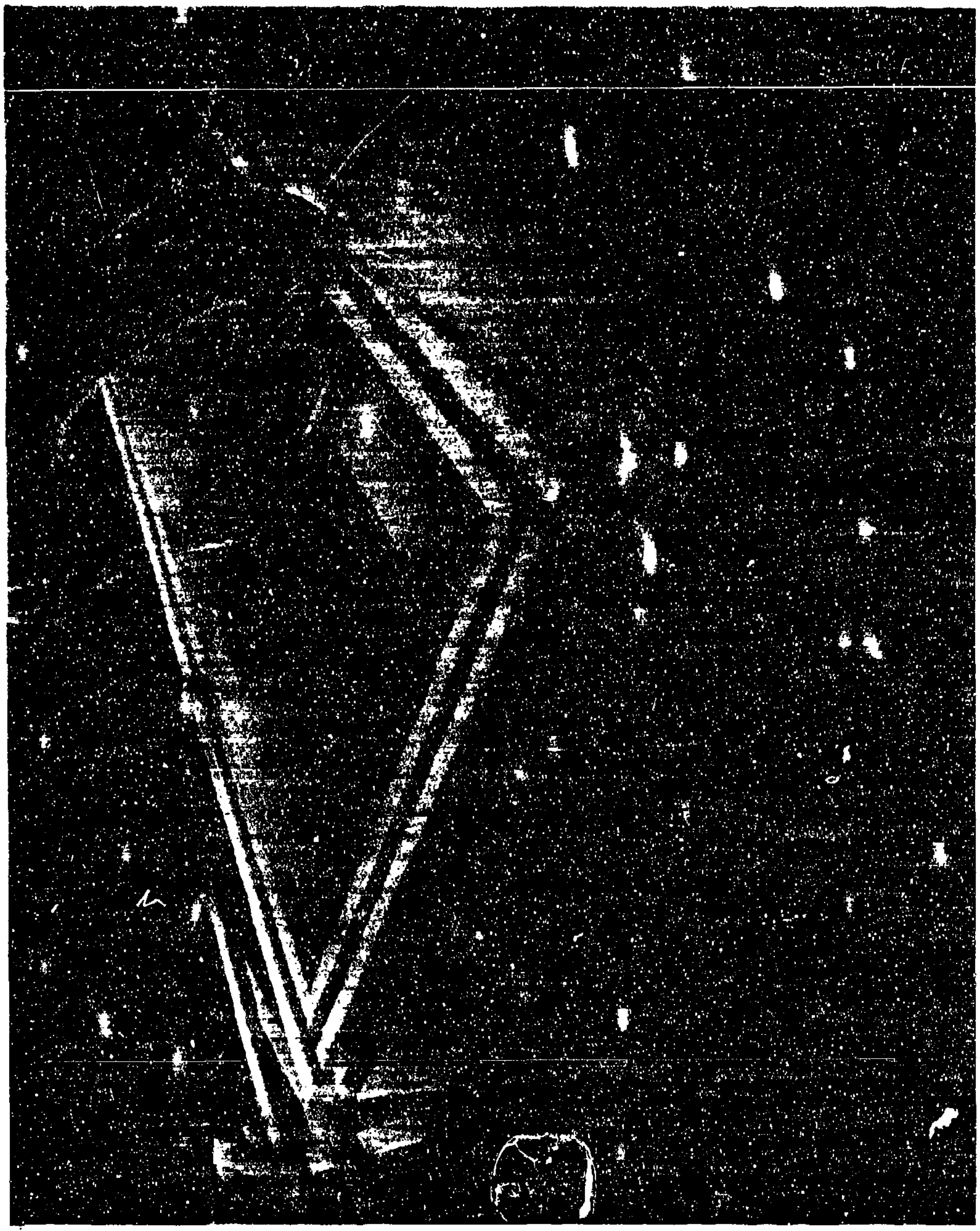


Fig. 17 Wall Tieing System

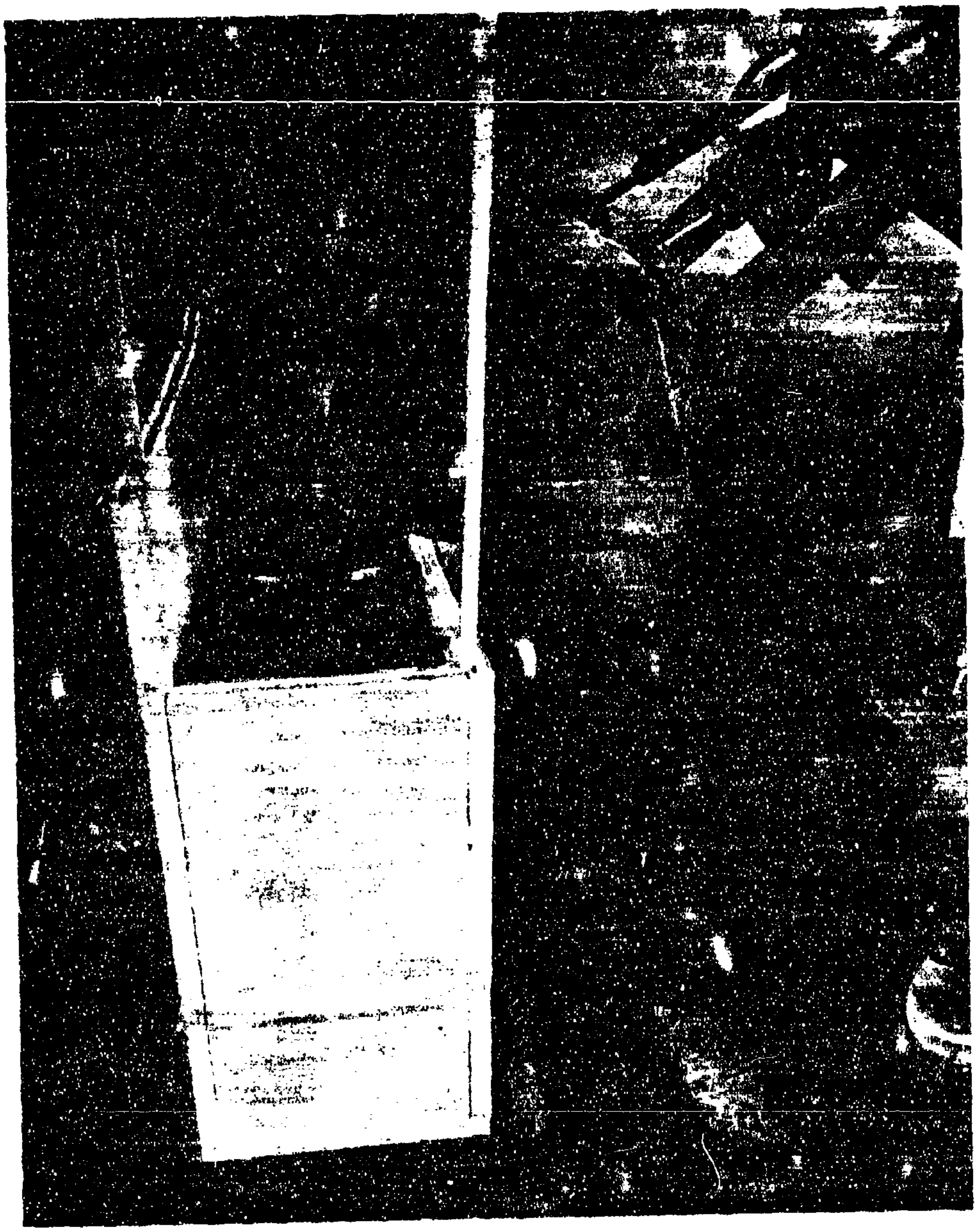


Fig. 18 Mechanical Loading Wet Sand

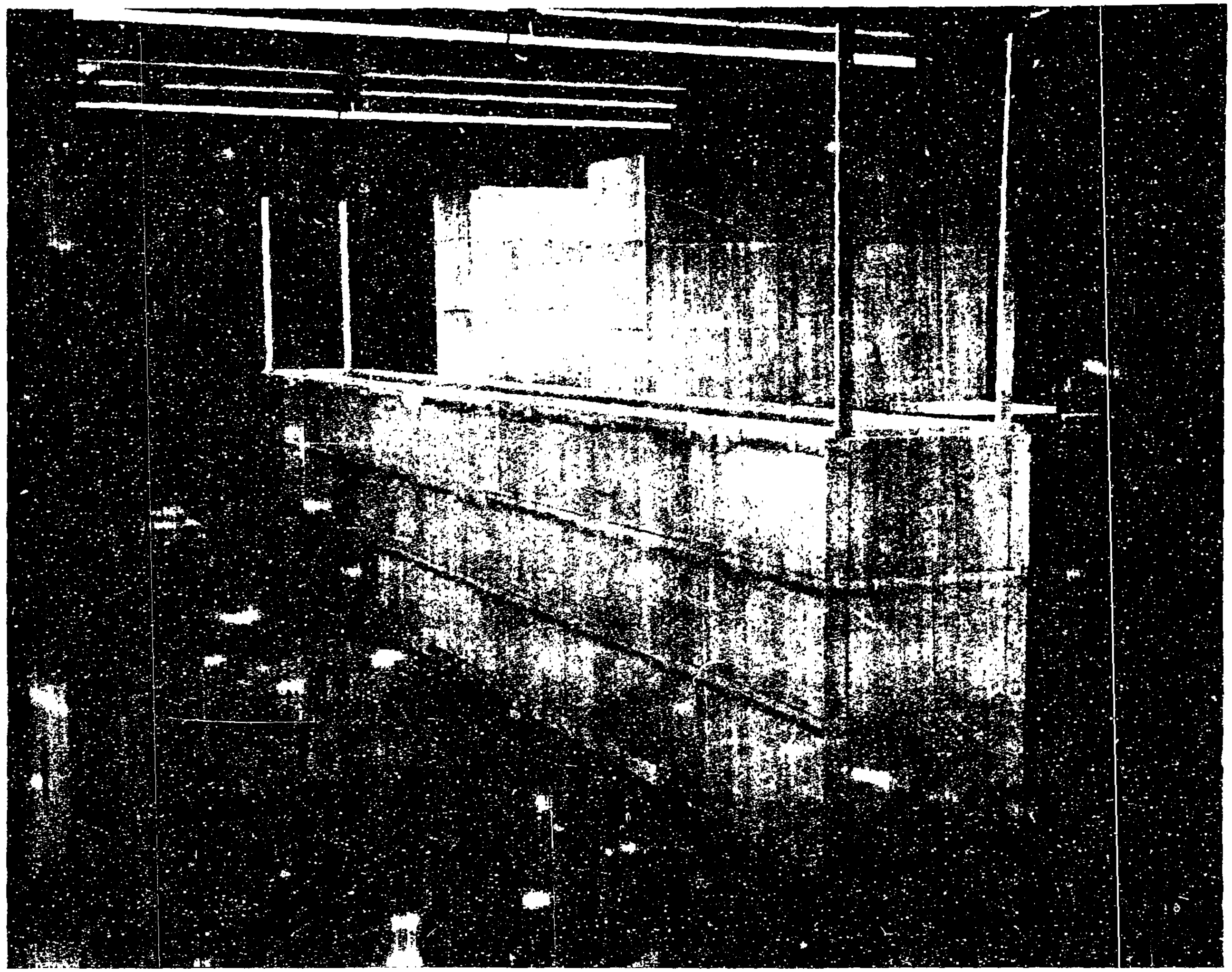


Fig. 19 Compartmented Storage During Assembly

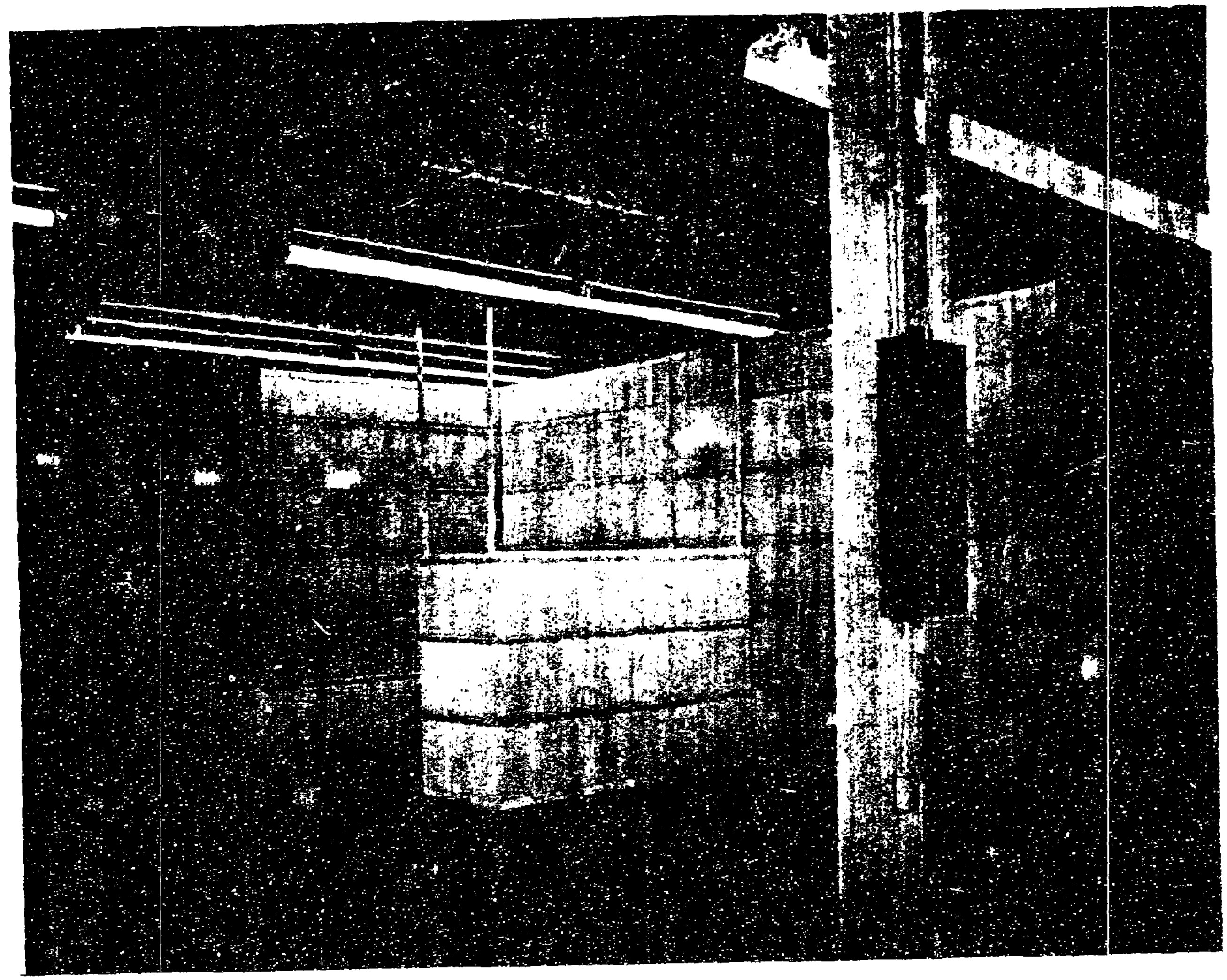


Fig. 20 Compartmented Storage Near Completion

Openings between adjoining center wall and wing wall are minimal when assembled plumb. When the supporting floor is sloped for drainage, it will be necessary to make a taper cut and regroove the bottom edge of the lower foam boards to establish a level top edge and a proper fit between wing wall and center wall.

Although satisfactory walls have been assembled with 2" and 3" thick boards, 3" walls are recommended for initial field installations.

A static electricity charge may be accumulated in the wall when loading dry sand with low relative humidity. Based on the research of Woodland and Ziegler "Static Dust Collection of Plastics", the wall can be effectively destaticized by spraying with a detergent. The hydroscopic detergent forms a moisture layer on the wall which conducts the charge to ground. The most effective destaticizer tested is Arquad 18 - 50 by Armour and Company, Chicago, Illinois.

It is recommended all barrier wall systems be sprayed after sand loading and before explosives are stored.

9. PACKAGING AND SHIPPING

Although a barrier system may be field fabricated from commercial foam board material, it is recommended a complete barrier system be prefabricated and packaged with assembly instructions for shipment to a storage site for installation. Packaging with coated Kraft paper or plywood boxes on pallets can be made compatable with commercial ISO containers and U. S. Air Force 463-L transport modes.

10. MAINTENANCE

The barrier walls are most vulnerable to damage during the assembly and explosives loading period. When required, the exposed wall ends may be protected with temporary plywood covers while the explosvies are being loaded.

Superficial wall punctures will not leak sand until the wall opening height is over one-half the wall thickness. Holes may be covered with pressure sensitive tape or they may be filled with plastic foam, rags or other light weight material.

Larger holes may be repaired by removing sand, trimming the opening, and plugging from the inside with a tapered block of plastic foam. More extensive damage is repaired by replacing with new boards. It is recommended spare foam boards be stored on top of the barrier walls for maintenance purposes.

11. COST

The cost of a complete pre-fabricated and packaged barrier system is estimated to be about $35.00 per linear ft. of barrier wall, not including freight.

12. FUTURE PROGRAM

An extension of the original government contract has been awarded for the installation of a demonstration barrier system at Earle, N. J. in October, 1971. This will be a 15 compartment wall system in a standard 80 ft. magazine. Tentative plans are being developed for installation of additional barrier systems for various other government agencies.

13. CONCLUSIONS

Commercial extruded polystyrene foam board wall structure is

a feasible and practical replacement for sand bag walls presently used for compartmented storage structures. The rigid foam board system is relatively simple to fabricate and assemble, and it provides for maximum space utilization. The initial cost in place is equivalent to present sand bag walls, and since the wall is relatively stable, virtually no maintenance is expected in the explosive storage mode.

This unique barrier system may be utilized in other applications such as personnel, aircraft or materiel protection from fragments either as a shielding wall or as an integral structural building wall.

14. REFERENCES

1. Department of Defense "Manual for Structures to Resist the Effects of Accidental Explosions", Technical Manual No. 5-1300, June 15, 1969.

2. Department of the Army. "Care, Handling, Preservation and Destruction of Ammunition" Technical Manual No. TM 9-1300-206, November 12, 1964.

3. Modern Plastics Encyclopedia "Foamed Plastics", McGraw-Hill, Inc., New York, New York, current issue.

4. Barkan, D. D. "Dynamics of Bases and Foundations" McGraw-Hill, Inc., New York, 1962.

5. Schneider, Klaus "Pressure Spreading and Pressure Distrubution in Bulk Goods", Chemical Engineering Technical Bulletin 41, p. 51-55, Aachin, Germany, 1969.

6. Merriman and Wiggins American Civil Engineers Handbook, Wiley and Sons, New York, 11th Ed., May 1948.

7. Timoshenko and Wornowsky-Krieger "Theory of Plates and Shells" McGraw-Hill, Inc., New York, 2nd edition, 1959.

8. Jenike, Andrew W. "Storage and Flow of Solids" Bulletin No. 123 Utah Experiment Station, University of Utah, Salt Lake City, Utah, March, 1967.

9. Woodland, P. C. and Ziegler, E. E. "Static Dust collection of Plastics". The Dow Chemical Company Technical Bulletin 3rd edition. November 1956.

10. ASTM C-203-58 "Breaking Strength and Calculated Flexural Strength of Preferred Block Type Thermal Insulation."

11. ASTM D-1621 "Test For Compressive Strength of Rigid Cellular Plastics".

12. ASTM C-273 "Shear Test in a Flatwise Plane of Flat Sandwich Construction or Sandwich Cores."

13. ASTM D- 1692 "Test For Flammability of Plastic Foams and Sheeting".

14. ASTM C-272 "Test For Water Absorption of Core Materials for Sandwich Construction."

AIR BLAST IN SUBDIVIDED STORAGE IGLOOS

D. C. Anderson

PRECEDING PAGE BLANK

AIR BLAST IN SUBDIVIDED STORAGE IGLOOS

1. Introduction

This talk is concerned with the experimental measurement of the air blast generated by the accidental detonation of the HE content of a single cell in a subdivided storage igloo. The first viewgraph (Fig. 1) shows a typical storage configuration studied.

Sandbag dividing walls have been evaluated for their performance in preventing transmission of detonation in a series of large-scale tests conducted at Hastings, Nebraska. On the basis of the results, criteria for safe storage have been developed which credit properly designed sandbag dividing walls with preventing cell-to-cell propagation of an explosion.

Reinforced-concrete dividing walls have also been considered for application in explosive storage structures to limit the propagation of accidental explosion from one storage unit to others. Since 1960, extensive experimental and analytical studies have been conducted on the effectiveness of concrete dividing walls in preventing propagation of an explosive accident. These studies included sensitivity tests of weapons to impact by primary and secondary fragments. Design methods have been developed for concrete dividing walls considering their dynamic response to explosive loading.

Initiation of an acceptor weapon may occur by air blast crushing or by impact of primary or secondary fragments. Secondary fragments are produced by spalling or scabbing of a wall due to primary fragment impact or to crushing of wall material during large deformations associated with dividing wall failure. As new weapons

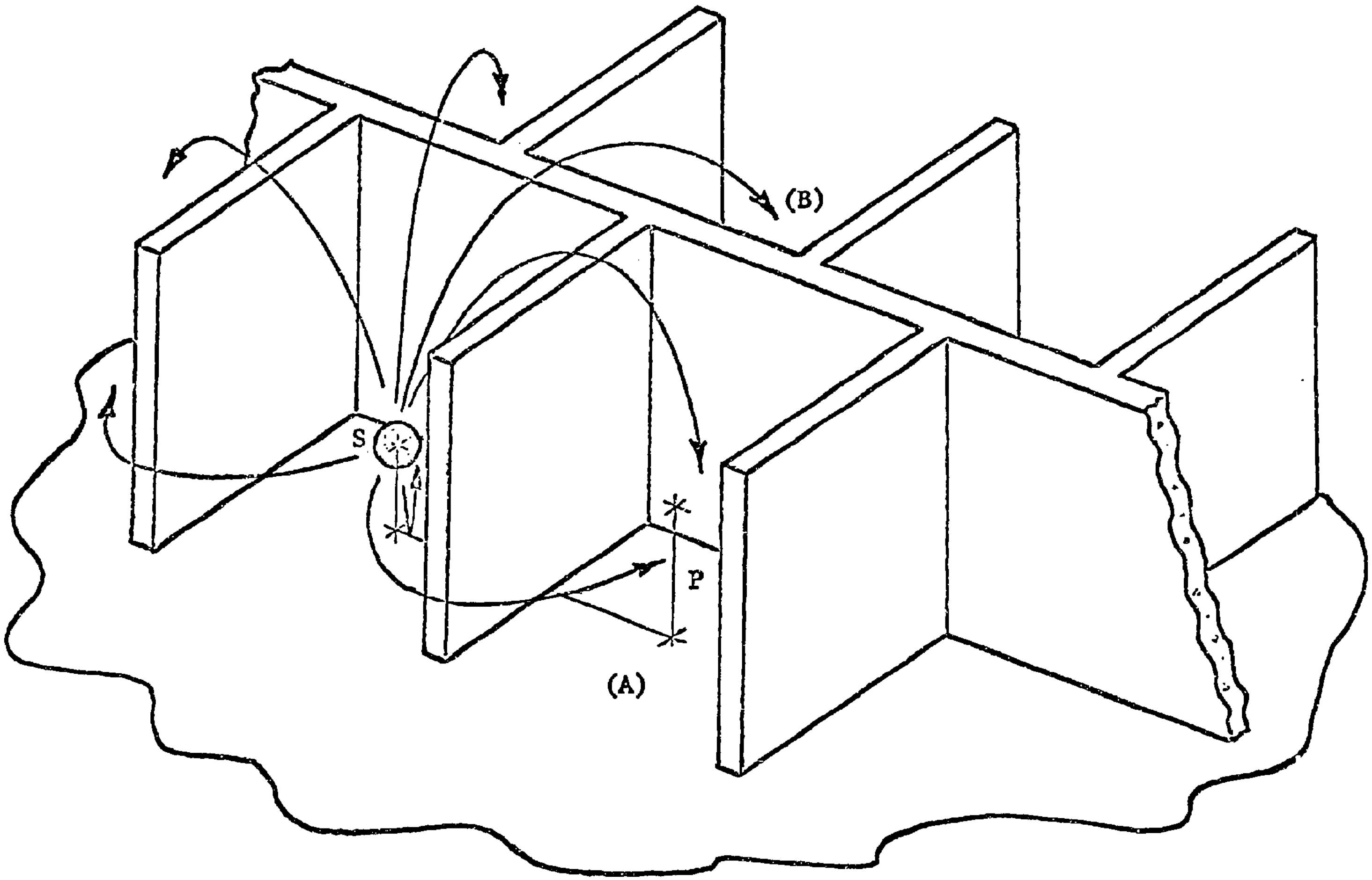


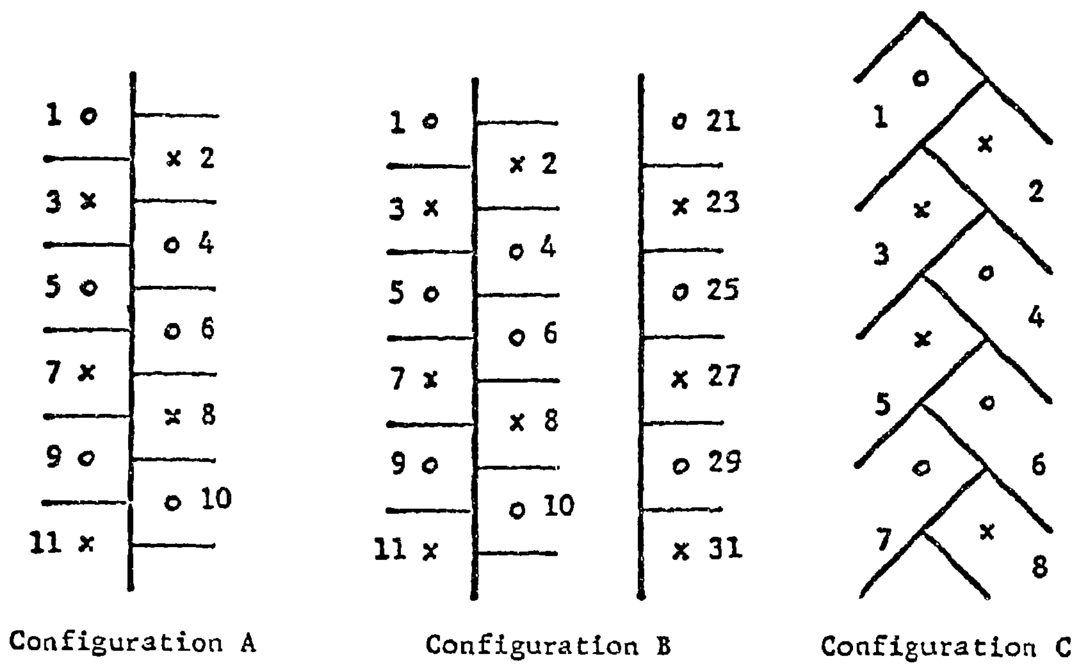
Figure 1   Typical Storage Cell Configurations

are introduced into the inventory, it is essential to have the capability to predict the sensitivity of the high-explosive components of the devices to stimuli arising from accidental detonation of an adjacent donor weapon.

This viewgraph shows nominally two types of storage cells, excluding special end cells. One adjacent cell, identified by the letter A, is on the same side of the center wall as the donor cell and the air blast wave entering the acceptor cell diffracts around the side of the barrier as well as over the top of the barrier. The other type of adjacent acceptor cell, identified by the letter B, is on the opposite side of the center barrier, and the air blast wave entering the cell diffracts only over the top of the center barrier.

2. Previous Studies of Air Blast in Sub-Divided Storage Igloos

Three basically different cell configurations are currently used in subdividing igloos with sandbag walls. One configuration, tested at Hastings, consists of cells arrayed along either side of a central longitudinal dividing wall; this will be termed the reference configuration. In another, an additional single row of cells along a longitudinal wall parallels the reference configuration; in the same igloo. In a third configuration, the cells form an angled herringbone array. The next viewgraph (Fig. 2) shows the three cell arrays. These arrays occupy igloos 60 ft in length. Configuration A (the reference geometry) and Configuration C apply to igloos 27 ft wide, while Configuration B applies to an igloo 40 ft wide.



x = Donor Cell

o = Gagé (Acceptor) Location

Figure 2 Cell Arrays for Weapon Storage Igloos

An experimental program now completed was conducted to determine the air-blast hazard at critical locations in these storage igloos in the event of explosion of a donor charge in one cell*. In this program all three cell configurations were studied. The relative intensity of blast loading in the three configurations were compared to identify the most favorable geometry for igloo subdivision.

Because airblast phenomena scale satisfactorily during the early-time period before significant gross motion of the dividing walls takes place, blast loadings in acceptor cells can be determined experimentally in rigid scale models of cell arrays. In hydrodynamic scaling, geometric lengths and event times are related as the cube root of the ratio of the explosive yields in the model and prototype. A one-tenth scale model of each cell arrangement does provide adequately resolvable pressure data using convenient (up to about 0.5 lb) charge weights for the model donors.

Therefore the experiments were performed using small explosive charges in rigid, one-tenth scale models of the subdivided igloos. Pressure measurements were made at several locations (see diagram - "acceptor" cells) in the array for each donor position, using transducers mounted centrally in the floor of the acceptor cells. Pressure gage signals were recorded on magnetic tape and time-correlated with the donor charge detonation.

*"Airblast In Subdivided Storage Igloos," Wiedermann, Anderson, and Nagumo, IITRI Final Report J6177, DASA 2598, December, 1970.

The test procedure was to record pressure-time histories in all acceptor cells simultaneously for each donor cell detonation. Each model was tested using the small charge weights (0.1 lb) first in order to maximize the number of shots completed before significant model damage prohibited further testing. This fact incidentally became more apparent as testing continued.

For the lower charge weight relatively little model damage was incurred. As the charge weight increased to 0.3 mild damage, i.e., weld cracking and some bolt shearing, was observed. The damage was most severe for the largest charge weights (0.5 lb). The model damage became extreme and required model modification.

The method of analysis which was used differed from that considered during the pretest planning phase in order to establish or group as many similar records of donor/acceptor situations together as possible. The principal variables of these types of problems are the explosive weight, the separation distance (perhaps slant range around the barrier), and the geometry, the latter being defined by a large number of specific variables. The end effects of the igloos will not be influential in the early portion of the blast environment due to their remoteness from many cells, hence use was made of several degrees of symmetry and/or the repetitious character of the geometries to minimize the number of donor cell/acceptor cell combinations.

An analysis of the results lead to the following conclusions and recommendations.

- The blast environment within Configuration B is the least severe of the three configurations examined. The maximum peak overpressure for all cells (except corner cells) is approximately 150 psi for an equivalent explosive weight of 125 lb of TNT.

- The blast environment within Configuration A was the next least severe with a maximum peak overpressure of approximately 290 psi for an equivalent explosive weight of 125 lb of TNT. Configuration C, with its herringbone arrangement of cells yielded the most severe blast environment of approximately 470 psi for the same equivalent weight of TNT.

- The proximity of the roof and/or side wall of the igloo is a major factor in controlling the peak overpressure within the storage cells. Corner cells did not appear to be the worst or controlling cells except for Configuration B where the roof was more remote than for the other configurations. The corner cells for Configuration B experienced a maximum peak overpressure of approximately 250 psi for an equivalent weight of 125 lb of TNT.

- The overpressure waveforms are quite complex due to the many reflections which occur. However, in many cases, only one or two large pressure peaks appear to occur and these frequently occur some time after the first arrival of the disturbance. The roof appears to be an important factor in the waveforms. The development of any simple predictive tool for storage cells in igloos does not appear to be feasible due to these many wave interactions.

Recommendations for improvement and/or additio al testing are as follows:

- Perform additional experiments on the cell arrangements of Configuration B to obtain blast environment data for the corresponding storage magazine which has a nearly flat roof. Include a better modeling of the end wall in which the access door is located.

- Use a gage block in the acceptor cell to evaluate the blast environment rather than locating a single pressure sensor in the central region of the floor. The gage block would be a rigid cube or short cylinder in which five pressure sensors would be located in the five principal directions. If this method is adopted then a few of the current experiments should be repeated to interrelate the two measuring systems.

3. Current Program on Air Blast in Subdivided Storage Igloos

IITRI is currently conducting follow on experiments to those just discussed. Figures 3 and 4 shown in the next viewgraph are photos of the model of Configuration B without a roof. In the current studies all of the experiments are being conducted with this model. Acceptor cell pressures are measured using Kistler gages on each of three faces of floor mounted gage blocks as seen in the viewgraph. The blocks are rotated 180 degrees to record the pressures on the remaining two exposed block sides.

In the current testing program charge weights of 0.1 lb and 0.2 lb are being fired. These charge weights reflect the HE content in the prototype. The charges are pressed spheres of C-4 and are mounted on cardboard standoffs, such that their c.g. is at the center of a donor cell. The viewgraph also shows a typical explosive charge on its mount.

Figure 3. No Roof Configuration Showing Gage Blocks and Charge

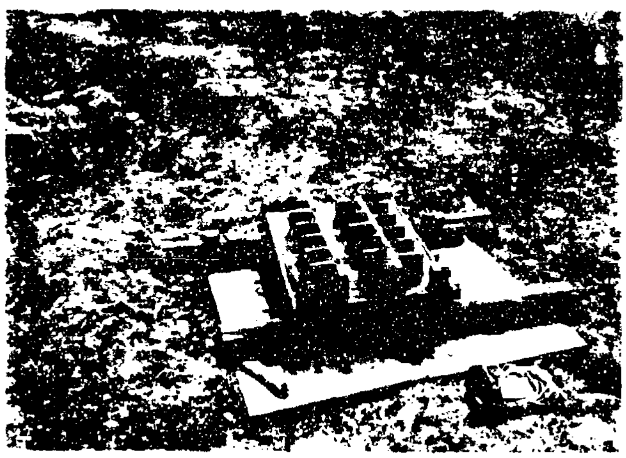


Figure 4. Overall View of Cell Configuration.

Figures 5 and 6 shown in the next viewgraph are photos of the model with its roof in place. The model was designed and constructed with easily removable roof parts or plates for easy access to its interior. This enables the experimentation to be carried out with a minimum delay between tests.

Figure 7, the next viewgraph, shows the two test configurations studied. The shot schedule was prepared based on both the results of the previous study, and consideration of what minimum number of donor-acceptor combinations must be tested to construct a full array of pressures expected from all donor-acceptor combinations.

On the current program a total of 59 tests have been completed, 47 with a roof and 12 without. All of these shots were fired using 0.1 lb charges. An additional 42 tests are currently being conducted with 0.2 lb charges.

The results of the 0.1 lb experiments, which scales up to 125 lbs of TNT in the prototype, are shown in the next three viewgraphs, Figures 8-10. The first donor-acceptor array shows those combinations in which the pressures do not exceed 150 psi. These are the maximum peak pressures as recorded on any of the exposed gage block faces. The second array shows those combinations in which the maximum peak pressures recorded were between 150 and 200 psi. The last viewgraph shows the combinations in which the pressures exceed 200 psi.

In presenting the results in this manner the least desirable donor-acceptor combinations are easily discernible.

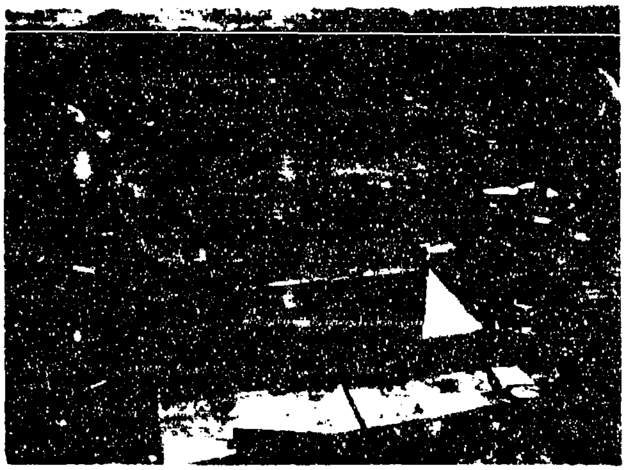


Figure 5. Igloo Model with Roof Axcess Parts Removed.

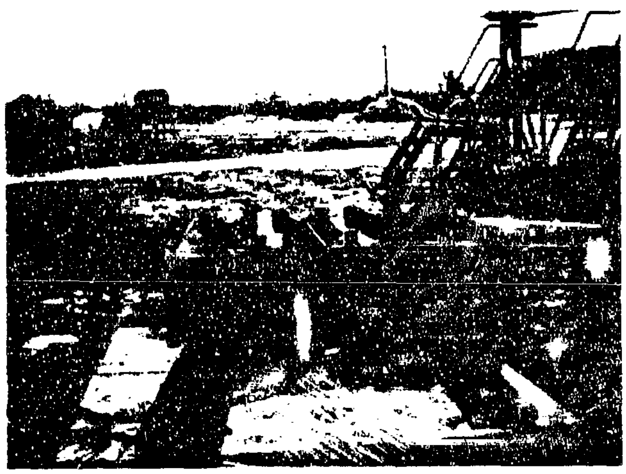


Figure 6. Igloo Model with Roof Covering.

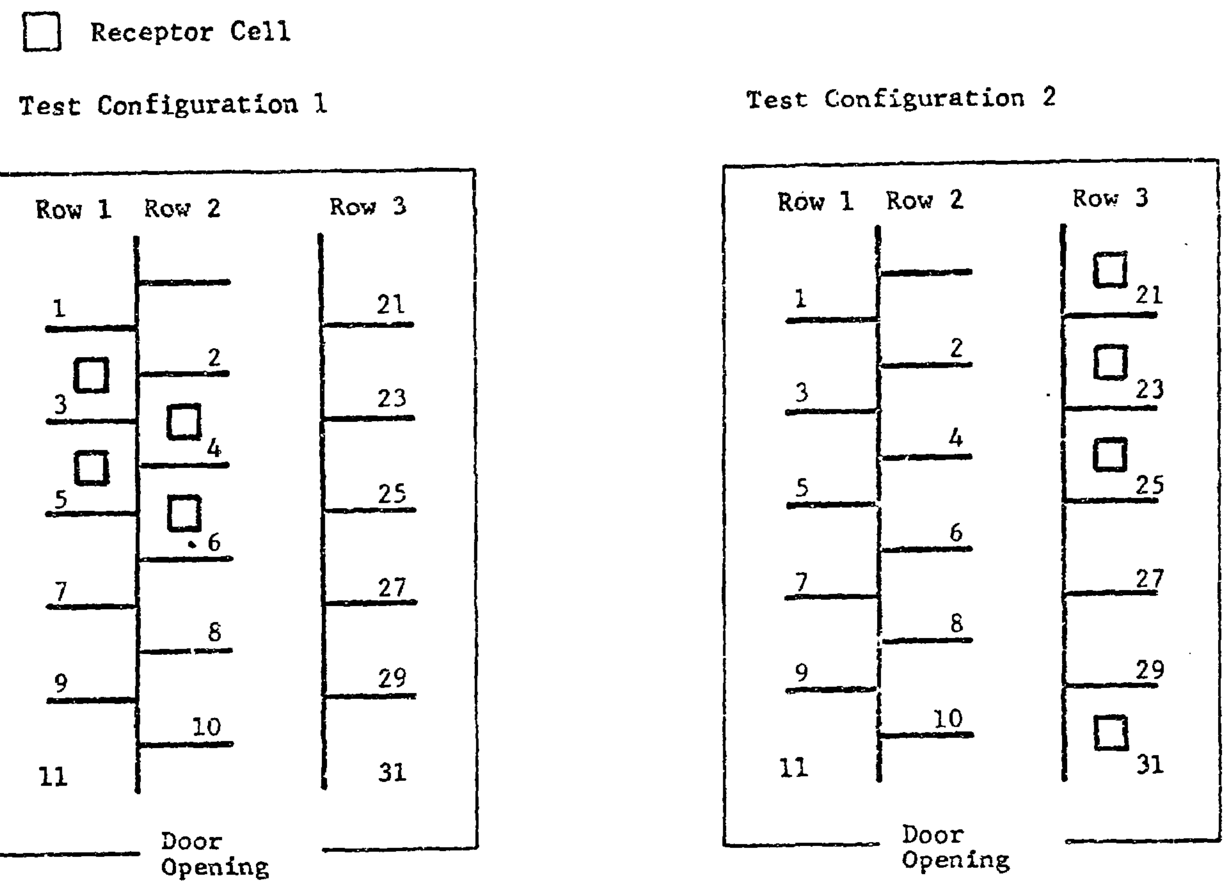


Figure 7 Test Configurations Studied

Figure 8 Maximum Peak Pressures Not Exceeding
150 psig - All Faces

Donor Cell \ Receptor Cell	1	2	3	4	5	6	7	8	9	10	11	21	23	25	27	29	31
1		X		X		X			X		X	X	X		X		
2	X		X							X			X	X	X		X
3		X		X		X		X			X			X	X	X	X
4			X		X								X	X	X	X	
5		X		X		X		X		X			X		X	X	X
6					X		X						X	X	X	X	X
7		X		X		X		X		X		X	X	X		X	X
8							X		X				X	X	X	X	
9	X			X		X		X		X			X	X	X		X
10		X							X		X	X		X	X	X	
11	X		X			X		X		X				X		X	X
21	X		X				X									X	X
23			X		X		X		X								X
25			X				X		X		X						
27	X		X		X				X		X						
29			X		X		X				X	X					
31					X				X		X	X	X				

Figure 9 Maximum Peak Pressures Between
150 and 200 psig - All Faces

Donor Cell	Receptor Cell																
	1	2	3	4	5	6	7	8	9	10	11	21	23	25	27	29	31
1							X	X		X				X		X	
2					X		X	X	X		X	X				X	
3									X	X		X					
4	X						X		X	X	X	X					
5											X	X					
6	X		X					X			X	X					
7	X																
8	X	X	X		X						X						X
9		X	X									X					
10	X		X	X	X		X						X				X
11		X		X	X							X	X		X		
21		X			X	X		X	X	X					X		
23	X	X		X				X		X							
25	X	X		X		X				X							X
27		X				X		X				X					
29	X	X		X				X		X			X				
31		X	X	X		X	X			X				X			

Figure 10 Maximum Peak Pressures Exceeding
200 psig - All Faces

Donor Cell \ Receptor Cell	1	2	3	4	5	6	7	8	9	10	11	21	23	25	27	29	31
1			X		X												X
2				X		X											
3	X				X		X						X				
4		X				X		X									X
5	X		X				X		X					X			
6		X		X				X		X							
7			X		X				X		X				X		
8				X		X				X		X					
9					X		X				X					X	
10						X		X									
11							X		X								
21				X							X		X	X			
23						X					X	X		X	X	X	
25					X			X				X	X		X	X	
27				X			X			X			X	X		X	X
29						X			X					X	X		X
31	X							X							X	X	

BLAST CRITERIA FOR PERSONNEL IN RELATION TO QUANTITY-DISTANCE*

D. R. Richmond and E. R. Fletcher
Lovelace Foundation for Medical Education & Research
Albuquerque, New Mexico

INTRODUCTION

For safety considerations it must be recognized that air blasts can produce injuries by three mechanisms: (1) from the overpressure effect itself; (2) from blast displacement of the individual; and (3) from missiles in the form of building debris, casing fragments, and crater ejecta that are hurled by the explosion. Thermal effects must also be considered in close proximity to small explosions.

To develop air-blast criteria for personnel, it is necessary to relate a selected effect (biological endpoint) with one or more of the physical parameters of the blast wave (the dose). In the weapons effects area, dose levels of air blasts have been determined that were lethal, that produced severe incapacitating injuries, that produced minimal injuries, and that produced no effect. This was done with a variety of biological species and the information provided the bases for predicting man's response to blast as a function of range and explosive yield. It is the objective of this paper to present some of these criteria in a form considered pertinent to the interests of the ASESB.

---

* This work was supported by the Defense Nuclear Agency of the Department of Defense.

The experimental work discussed in this manuscript was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences-National Research Council.

This paper will give blast criteria for man standing in the open, primarily for the direct overpressure and displacement effects in terms of quantity-distance. In order to put these criteria in the proper perspective, some information on crater ejecta will be included. Blast effects for personnel inside structures will also be discussed.

AIR-BLAST CRITERIA FOR PERSONNEL STANDING IN THE OPEN

Selected air-blast criteria that apply to people standing in the open are presented in Table 1. They apply to classical blast waves with the shock front perpendicular to the surface and are based on data in References 1–3. The criteria are for overpressure effects and for displacement effects. The overpressure effects are eardrum rupture, lung hemorrhage, and 1-percent mortality. The dose is in terms of the peak pressure and the level required depends upon the duration. At shorter durations the peak pressure required for a given effect is much higher than at the longer durations. Lung hemorrhage and 1-percent mortality may be expected to occur at peak pressures of 10 and 27 psi for blast waves with durations longer than 50 msec compared to 20–30 and 60–70 psi, respectively, for blasts of about 3-msec duration. Eardrum rupture does not seem to be duration sensitive except possibly for blast waves of very short duration—less than 1 msec.

The blast displacement criteria in Table 1 are: no personnel blowndown, a 50-percent probability of blowndown, and a 1-percent probability of serious injury from blast displacement. The dose is in terms of the dynamic-pressure impulse necessary to impart a given peak velocity to a standing man. It was assumed that a peak horizontal velocity of 0.3 ft/sec would not cause a person to fall over but a velocity of 2 ft/sec would, in half the cases. At 13 ft/sec there would be a 1-percent incidence of serious injuries from decelerative tumbling in the open.

TABLE 1

AIR-BLAST CRITERIA FOR PERSONNEL
STANDING IN THE OPEN

Criteria	Physical Parameters (dose)	Remarks
Direct Overpressure Effects:		
1% Eardrum Rupture	3.4 psi	Not duration sensitive except possibly for durations of less than 1 msec. Not a serious lesion.
50% Eardrum Rupture	16.0 psi	Some of the ear injuries would be of a severe form.
Threshold Lung Hemorrhage	10.0 psi	10 psi applies to blasts of long duration, over 50 msec; 20–30 psi required for 3-msec duration waves; not a serious lesion.
1% Mortality	27 psi	27 psi applies to blasts of long duration, over 50 msec; 60–70 psi required for 3-msec duration waves. A high incidence of severe lung injuries.
Displacement Effects:		
No Personnel Blowndown	1.25 psi·msec	At this dynamic-pressure impulse, man would attain a peak horizontal velocity of 0.3 ft/sec.
50% Probability of Personnel Blowndown	8.30 psi·msec	At this dynamic-pressure impulse, man would attain a peak horizontal velocity of 2.0 ft/sec.
1% Probability of Serious Injury from Being Blowndown	54 psi·msec	At this dynamic-pressure impulse, man would attain a peak horizontal velocity of 13 ft/sec; serious injury (bone fracture or rupture of internal organs) could occur from impact with the ground; high probability of minor injuries such as bruises and lacerations.

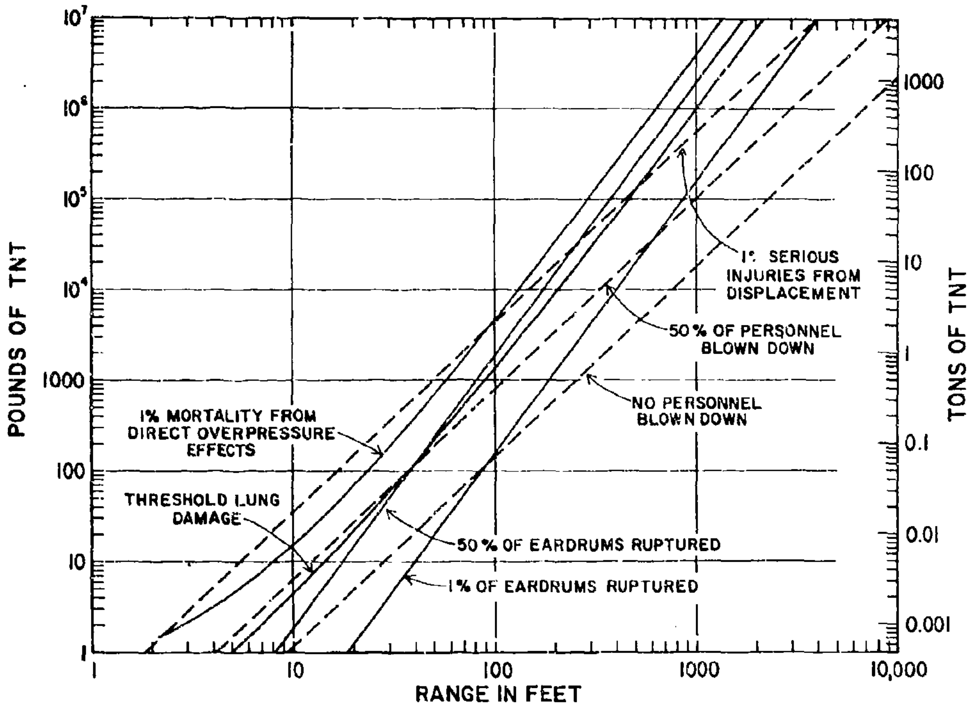


Figure 1. Air-Blast Criteria for Personnel Standing in the Open.

Curves relating these blast criteria to quantity-distance were computed. The pressure-time parameters for the overpressure effects curves were based on data in Reference 4, assuming 1.0 pound of Pentolite equivalent to 1.1 pounds of TNT and a ground reflection factor of 1.8 for a surface burst. The dynamic-pressure impulses were an average of those given in References 5 through 8. The average impulse was obtained by the formula

$$\ln(R) = \left[5.4054 + 1.1067 \ln(W) - \ln(I)\right]/2.3201$$

where R is the range in feet, W is the yield in pounds of TNT, and I is the dynamic-pressure impulse in psi·msec.

It can be seen in Figure 1 that for very small charges (100 lbs or less) the "1-percent probability of eardrum rupture" curve falls to the right of the "no personnel blown down" curve. The latter represents the closest ground range where people would not be expected to be blown down by the blast. One-percent probability of eardrum rupture can be the most far-reaching blast effect for yields up to about 15 tons. For yields greater than 15 tons, the 50-percent probability of personnel blown down extends to the greater distances. For explosions of 70 tons or more, serious injuries from displacement can be expected beyond the range for all overpressure effects except eardrum rupture.

CRATER-EJECTA CRITERIA FOR PERSONNEL IN THE OPEN

Equations for the maximum range for crater ejecta and the density of missiles associated with a 1- and 50-percent probability of being struck by them appear in Table 2. Curves relating these parameters to quantity-distance are illustrated in Figure 2.

The equations for the maximum ranges for rock and soil ejecta from half-buried spheres were taken from Reference 9. They are:

$$R_{max} = 70W^{0.4} \text{ for rock medium, and}$$

$$R_{max} = 30W^{0.4} \text{ for soil medium}$$

TABLE 2

CRATER EJECTA CRITERIA FOR PERSONNEL IN THE OPEN

Maximum Range for Rock Ejecta	$R_{max} = 70W^{0.4}$ *
1% Probability of Being Struck by Ejecta	600 ft^2/missile
50% Probability of Being Struck by Ejecta	9 ft^2/missile

* $R_{max} = 30W^{0.4}$ for soil medium.
R is in ft and W is in pounds of TNT.

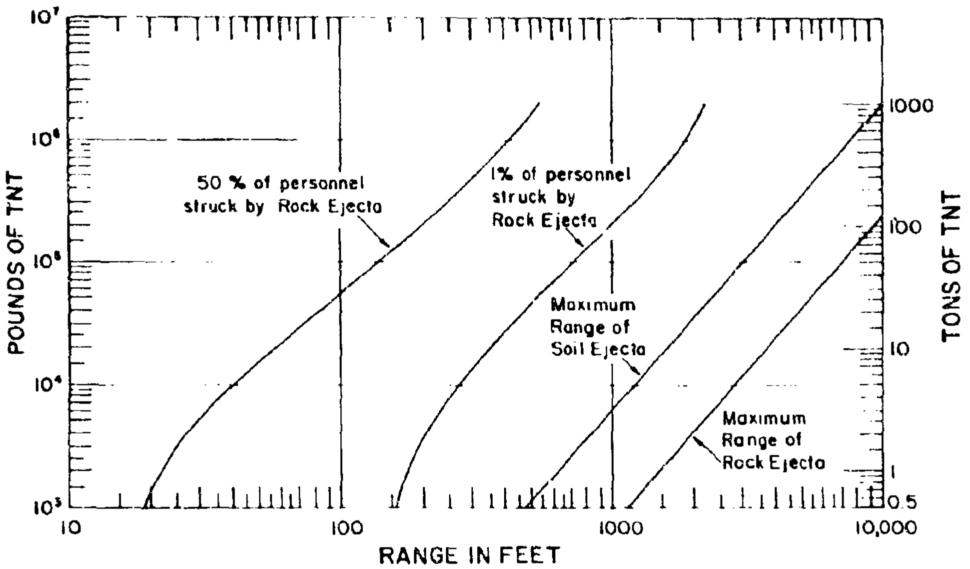


Figure 2. Crater-Ejecta Criteria for Personnel in the Open.

where R_{max} is in feet and W in pounds of TNT. The formulae are based on observed maximum ranges from a limited number of explosions. It was recommended in Reference 9 that for safety considerations it is advisable that the maximum ranges be multiplied by 1.5 or 2.

The probabilities of being struck by ejecta depend on the density of ejecta, usually given in terms of specific area, "A," and the projected area, "a," of man. If the missiles are small in size compared to man, the probability that at least one missile will strike him is approximately equal to

$$1 - e^{-a/A}$$

where "a" is in ft^2 and "A" is in ft^2/missile. The maximum value for the projected area of man, approximately 6.2 ft^2 (corresponding to a face-on or back-on orientation to the impacting missiles), was used for "a." From the above, it can be shown that approximately 1 and 50 percent of the people would be struck by ejecta for specific areas of 600 and 9 ft^2/missile, respectively.

Curves for 1- and 50-percent probabilities of being struck by ejecta were estimated from data on specific area as a function of range and yield reported in Reference 10. These data were obtained in the discontinuous portion of the ejecta mass and all discrete masses of rock greater than 0.5 lb were included.

As the range decreases, the missile masses tend to increase and the averages are well above 0.5 lb. Therefore, the ranges for 1- and 50-percent probabilities of being struck by rock ejecta may not be far from the ranges for 1- and 50-percent probabilities of being seriously injured by the ejecta, regardless of the yield. For safety purposes it can be assumed that a missile-hit would be dangerous and likely damaging regardless of the part of the body struck.

Curves could not be drawn for various probabilities of being struck by soil ejecta because densities for dirt ejecta are normally given in terms of an average value of lb/ft^2, rather than in terms

of specific area. As in the case of maximum ranges, it is expected that the ranges for injuries from impacts with soil ejecta would be less than the corresponding ranges for rock ejecta.

If an explosive charge is cased, the maximum range of the resulting fragments may be greater than the maximum ejecta range. An expression that has often been used for casing fragments is

$$\text{safe distance} = 600 \, W^{1/3}$$

where distance is in feet and W in pounds of TNT (Reference 11). This formula gives only a rough estimate, however, and fragments have been observed beyond the predicted limits.

As seen in Figure 2, the three curves for rock ejecta in relation to quantity-distance are widely separated. There would be a considerable difference in the maximum distance rock ejecta might travel from an explosion and the range where the ejecta would have the area coverage associated with a 1-percent probability of striking a personnel target. In the case of a 5-ton explosion, the maximum range for rock ejecta was about 2800 feet whereas the range for a 1-percent probability of being hit by ejecta was around 270 feet.

AIR-BLAST EFFECTS ON PERSONNEL INSIDE STRUCTURES

For personnel inside structures, the effects from the overpressure, blast displacement, and structural collapse must be considered. This section will deal only with the blast overpressure effects in structures that are relatively blast-hardened. At the present time, there is insufficient information to develop criteria for blast displacement effects on personnel inside structures. Injuries from building damage or flying glass may be one of the more far-reaching safety problems for people in structural complexes.

The shape of an air blast wave is altered upon entering a structure. The biological effects depend on the details of the

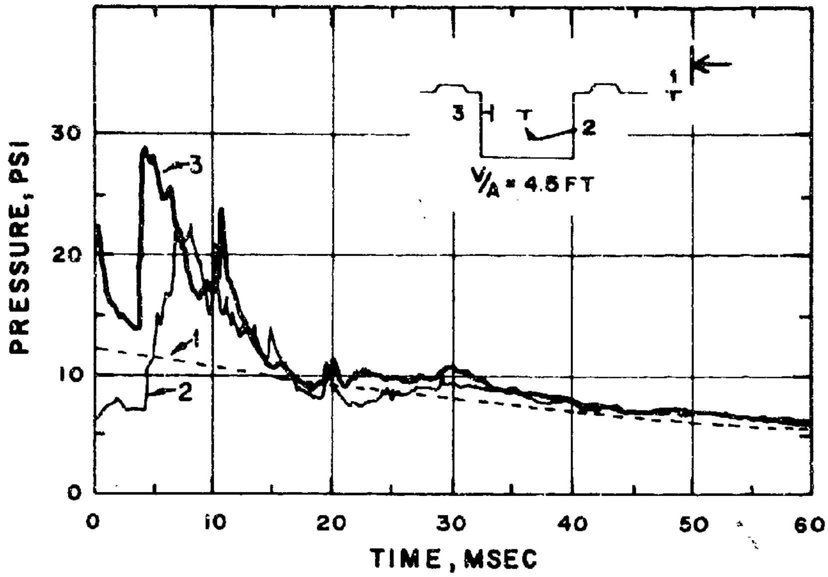
pressure-time pattern inside the chamber. This waveform is governed by such factors as the ratio of the chamber volume to the area of the entrance (V/A ratio), the orientation of the openings, and the intensity of the outside wave. The blast wave in a structure consists of two parts: the diffraction phase, which is the entering shock front and its reflections; and the fill phase, which is a smooth rise in pressure.

For study purposes, structures may be grouped into one of three categories in terms of their V/A ratios. These are: (1) foxhole-type emplacements that have V/A ratios of 20 feet or less; (2) bunker-type structures that have V/A ratios on the order of 30 to 60 feet; and (3) shelters that have V/A ratios of several hundred feet.

As seen in the upper portion of Figure 3, the blast waves typically recorded in foxhole-type emplacements have reflected shock waves at the leading portion of the wave well above the magnitude of the outside shock wave. The fill-phase portion of the wave is relatively insignificant compared to the diffraction phase.

Figure 3 shows the pressure-time pattern recorded in a 12- x 12- x 8-foot room filled through a 3- x 6-foot door (V/A ratio of 66 feet). The waveform is similar to those recorded in an open bunker. The peak pressure in the reflected shock waves is about equal to that of the fill phase; both are approximately half the magnitude of the outside wave. The peak pressure inside some bunker configurations with smaller V/A ratios may be above that in the outside wave when the opening faces the detonation.

Also shown in Figure 3 is the pressure-time pattern recorded inside the other room of the shelter (V/A ratio of 175 feet) which filled through a 3-foot diameter opening. The wave was characterized by weak initial shocks and reflections on the order of one-tenth that in the outside wave with the peak pressure occurring in the fill-phase portion of the wave. The peak pressure in the fill-phase was about one-fifth that of the outside wave with a long time-to-peak pressure.



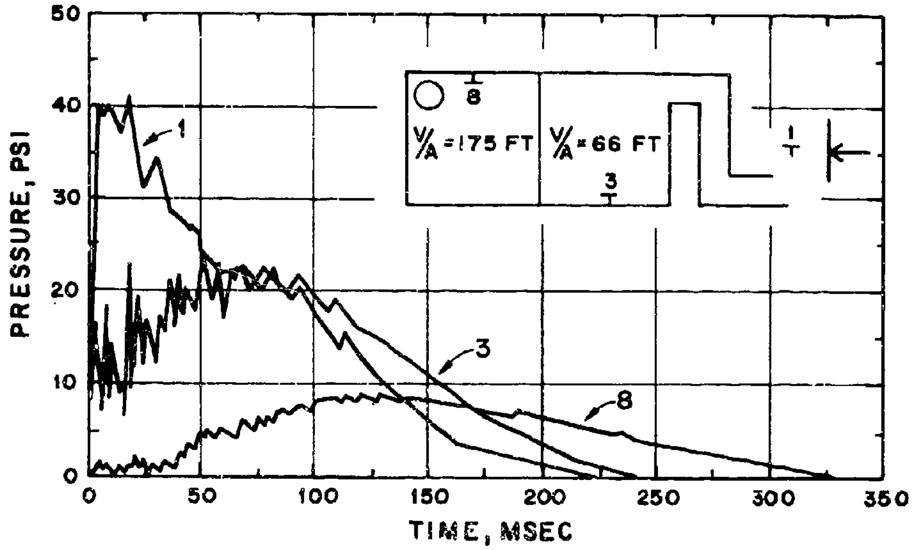


Figure 3. Upper: Pressure-Time Patterns Recorded Inside an Open Two-Man Foxhole 830-Feet from a 500-Ton TNT Explosion. Lower: Pressure-Time Patterns Recorded Inside an Open Underground Personnel Shelter Subjected to a Nuclear Blast.

Diffraction Phase

Recent studies (Reference 12) have provided some information on the tolerance of animals to reflecting shock waves. By placing animals against the endplate of a closed shock tube and at distances of up to 5 feet from the endplate, it was possible to subject them to an incident and reflected shock front separated by time intervals that were a function of the animal's distance from the reflecting surface. It was found that for sheep against the endplate or 1/2 foot from the endplate, wherein the time between the incident and reflected shocks ranged from 0 to 0.8 msec, the LD_{50} reflected pressures were about the same—45 to 50 psi, Figure 4. At 2 feet or more from the reflecting surface, with time steps of 3 msec or more, the LD_{50}'s were on the order of 75 to 85 psi. In general terms, the LD50 reflected pressure for sheep increases 80 to 100 percent when a few milliseconds separates the shock fronts in the diffraction phase of the blast wave.

The same sort of thing was found regarding lung hemorrhage. The levels where threshold lung injury and slight lung hemorrhage occurred were at least 10 psi higher for sheep that received waveforms in which there were a few milliseconds between the incident and reflected shock waves than for those subjected to waves with less than 1-msec time intervals between shocks. This was not true for eardrum rupture.

The data indicated that the eardrum rupture in sheep was related to the peak reflected pressure. Time steps between shocks did not alter eardrum response as it did for lung injury and mortality.

Fill Phase

Animals have demonstrated a remarkable resistance to smooth-rising pressures similar to the fill-phase portion of a blast wave recorded in structures. In modified shock tubes, dogs and monkeys have been exposed to smooth-rising pressures wherein the peak pressure and time-to-peak pressure were varied. In one study subjects received peak pressures of either 10, 20, 50, or 100 psi. The times-to-peak pressures within each group were 15–20, 30, 80–90

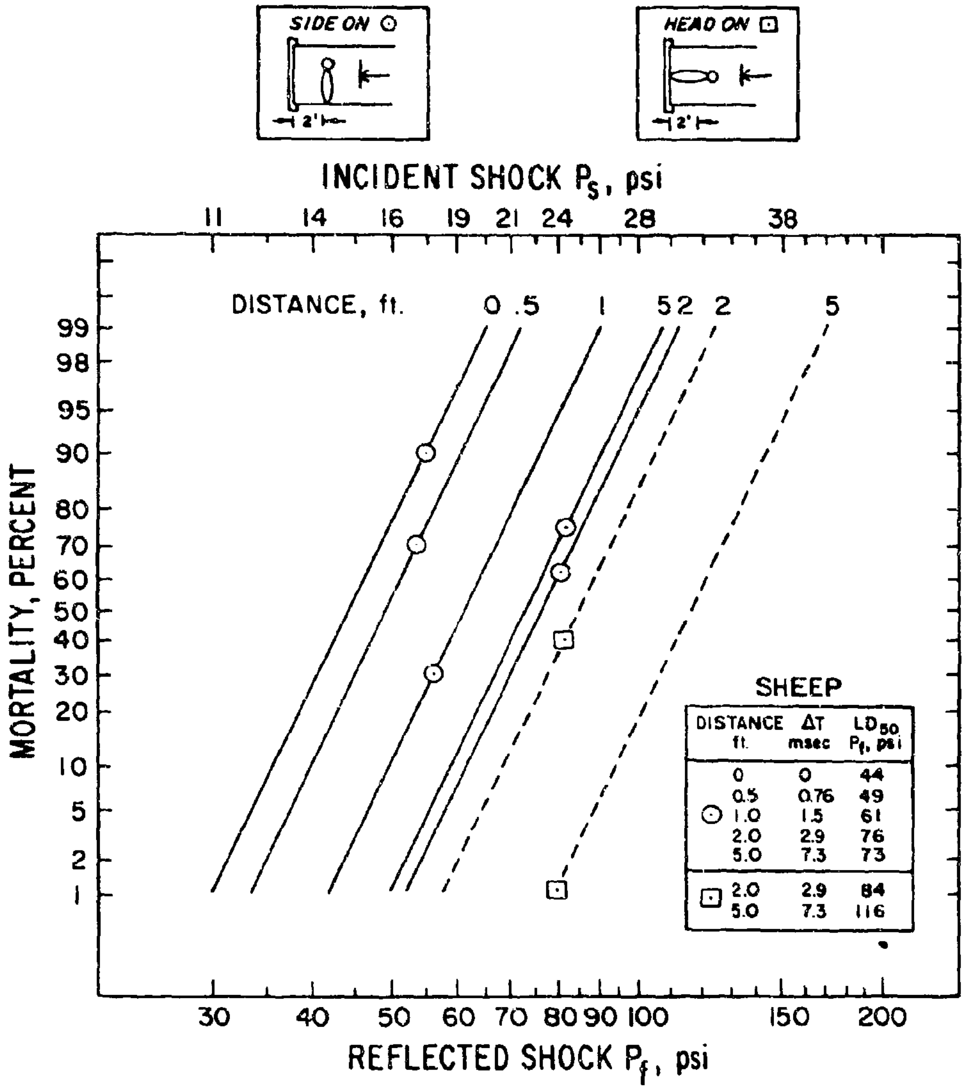


Figure 4. Probit Mortality Curves for Sheep Subjected to Air Blasts at Various Distances from a Reflecting Surface.

and 200–400 msec. These data, taken from Reference 13, are summarized in Figure 5. All the specimens survived these pressure-time patterns. It was only at the highest pressures and at the two shorter rise time groups that slight lung hemorrhages occurred. The most significant finding was eardrum rupture which ranged in severity in proportion to the magnitude of the pressure. There was a low incidence of eardrum rupture in the subjects that received 20 psi and below—this was the only blast lesion found in those specimens. In general, there was a lower probability of eardrum rupture for smooth-rising pressures than for those with a shock front at the leading edge. However, smooth-rising pressures as low as 10 psi did cause eardrum rupture in dogs, the probability of this lesion occurring at low pressures was about the same as that for fast-rising blast waves. The 1-percent probability of eardrum rupture was 4.3 psi for smooth-rising pressures compared to 3.7 psi for the ones that rose near simultaneously.

One-Seventh Scale Model Studies

Foxhole-type structures of various designs containing rats have been tested in a shock tube. The models were one-seventh scale based on the cube root of the ratio of man's body weight to that of the rat: $(70\text{kg}/0.2\text{kg})^{1/3}$. Calibration curves were compiled that related the magnitude of the reflected shocks on the walls and bottom of these foxhole models to the outside incident shock wave. Based on data obtained with rats near the endplate of the shock tube (analogous to the studies already mentioned using sheep, Figure 4), it was possible to correlate the blast response of rats inside the models with the corresponding pressure-time patterns.

There was good agreement between the waveforms recorded in these scale models and those recorded in full-scale versions of them on field tests involving 500-ton explosions. Consequently, it appears possible to predict the wave shape inside a given structure as a function of the incident shock wave from scale model

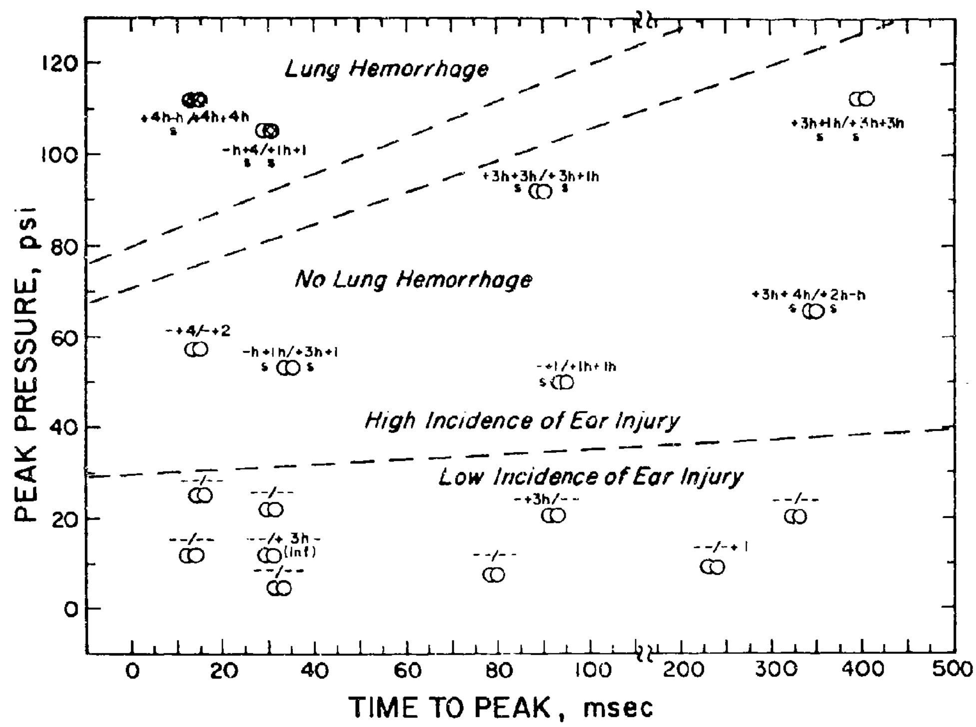


Figure 5. Distribution of Blast Injuries in Dogs in Relation to Peak Pressure and Time-to-Peak Pressure.

⊗ = lung hemorrhage
s = sinus hemorrhage

Other "-" or "+" symbols are for degrees of ear injury:

- \- = eardrums intact
- h = hemorrhage
- +1 = eardrums less than 25% destroyed
- +2 = eardrums between 25 and 50% destroyed
- +3 = eardrums greater than 50% destroyed
- +4 = eardrums greater than 50% destroyed with malleus fractured or disrupted.

(From Reference 13).

tests in a shock tube. This together with the response data for sheep permits predicting the outside pressure levels required to produce a given effect on personnel in a particular structure.

Blast Criteria for Personnel in Foxhole-Type Structures

Using the techniques described above, blast criteria for personnel inside uncovered foxholes were compiled, Table 3. The pressures apply to that measured side-on on the ground surface and to blast waves of classical form. Injuries from blast displacement inside this type of structure would not be expected to occur at pressures below those that cause damage from the direct overpressure effects. In general, these numbers can apply to partly covered foxholes that have their openings toward the blast source. Structures with a partial cover and the opening at the downstream end would be much safer. As seen in Table 3, there would be a 1- and 50-percent probability of eardrum rupture in occupants of foxholes at 1.5–2.0 and 7–8 psi, respectively. If ear protectors can be worn, pressures as high as 8 psi would not be injurious. There would be a low and high probability of slight lung injury at 10 and 13 psi, respectively. This level of lung hemorrhage does not constitute a serious injury.

At the present time work is underway to develop blast safety criteria for personnel inside bunkers and shelters; both from the standpoint of direct overpressure effects and blast displacement effects.

TABLE 3

AIR-BLAST SAFETY CRITERIA FOR PERSONNEL INSIDE UNCOVERED FOXHOLE-TYPE STRUCTURES

Criteria	Side-On Pressure,* psi
1 Percent of Eardrums Ruptured	1.5–2.0
50 Percent of Eardrums Ruptured	7–8
No Lung Injury	8
Low Probability of Slight Lung Injury	10
High Probability of Slight Lung Injury	>13
50-Percent Mortality	25–30

*Shock front perpendicular to the surface.
Applies to explosive yields of over 1 ton.

REFERENCES

1. Bowen, I. G., E. R. Fletcher, and D. R. Richmond, "Estimate of Man's Tolerance to the Direct Effects of Air Blast," Technical Progress Report, DASA-2113, Defense Nuclear Agency (formerly Defense Atomic Support Agency), Department of Defense, Washington, D. C., October 1968.

2. Hirsch, F. G., "Effects of Overpressure on the Ear—A Review," Technical Progress Report, DASA-1858, Defense Nuclear Agency (formerly Defense Atomic Support Agency), Department of Defense, Washington, D. C., November 1966.

3. Fletcher, E. R., D. R. Richmond, and R. K. Jones, "Project LN402—Blast Displacement of Dummies in Open Terrain and in Field Fortifications," to appear in Proceedings The Event Dial Pack Symposium, March 30—April 1, 1971, Ottawa, Canada.

4. Goodman, H. J., "Compiled Free-Air Blast Data on Bare Spherical Pentolite," Report No. 1092, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, February 1960.

5. Brode, Harold L., "A Calculation of the Blast Wave from a Spherical Charge of TNT," Research Memorandum, RM-1965, ASTIA AD-144302, The Rand Corporation, Santa Monica, California, August 1957.

6. Keefer, John H., "Air Blast Predictions for Operation Distant Plain," Technical Note No. 1612, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, June 1966.

7. Fletcher, E. R., et al., "An Estimation of the Personnel Hazards from a Multi-Ton Blast in a Coniferous Forest," Final Report, DASA-2020, Defense Nuclear Agency (formerly Defense Atomic Support Agency), Department of Defense, Washington, D. C., November 1967.

8. Needham, Charles E., "Prairie Flat Air Blast Calculations," AFWL-TR-69-4, Air Force Weapons Laboratory, Air Force Systems Command, Kirtland Air Force Base, New Mexico, February 1969.

9. Vortman, L. J., "Maximum Missile Ranges from Surface and Buried Explosions," TID-4500 (50th Ed.), Sandia Laboratory, Albuquerque, New Mexico, September 1967.

10. Henny, R. W. and R. H. Carlson, "Distribution of Natural Missiles Resulting from Cratering Explosions in Hard Rock," Ann. N. Y. Acad. Sci. 152: 404-431, (October 28) 1968.

11. Bishop, R. H., "Maximum Missile Ranges from Cased Explosive Charges," SC-4205(TR), Sandia Corporation, Albuquerque, New Mexico, July 1958.

12. Richmond, D. R., E. R. Fletcher, and R. K. Jones, "LN401 – Blast Protection Afforded by Foxholes and Bunkers," to appear in the Proceedings of The Event Dial Pack Symposium March 30–April 1, 1971, Ottawa, Canada.

13. Richmond, D. R., "Blast Effects Inside Structures," to appear in Proceedings Second Conference on Military Applications of Blast Simulators, November 2–5, 1970, Naval Weapons Laboratory, Dahlgren, Virginia.

A NOTE ON FRAGMENT INJURY CRITERIA *

by

William Kokinakis
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

*Extracted from BRL Technical Note No. 1645, "Ballistic Limits of Tissue and Clothing," dated January 1965, J. Sperrazza and W. Kokinakis

PRECEDING PAGE BLANK

Introduction

When a high explosive munition detonates, the casing that surrounds the explosive charge is fragmented and is projected outwards at high speed. The fragments often are irregularly shaped, weigh from fractions to hundreds of grams and move at speeds as high as several thousand meters per second. Because of practical considerations of designing and developing for soldiers diverse armoring materials (such as body armor, helmets and their liners and other protective gear), and because of hazards associated with the accidental detonations of munitions on production lines, in transit, in storage or in use, we decided to try to evolve a criterion for predicting the likelihood that if a person is struck by any of these fragments (or missiles) that it would perforate (completely traverse) the skin and subcutaneous tissue. If such perforation occurs then the residual speed of the missile usually is sufficient to cause a significant wound. Fortunately, experimental facilities (and indeed some data) were available from other studies[1] so that the experimental portion of the task was not difficult.

A Simple Theory of Penetration

To attempt an exact solution of our problem from first principles is beyond present state-of-the-art and certainly beyond the intended scope of this paper. The problem is a three dimensional, non-steady state problem. Among many complicating factors is the non-availability of suitable constitutive equations (equations of state). Yet the authors felt that a simple, one-dimensional approach might yield something useful.

Consider a non-deforming projectile or missile penetrating a medium such as gelatin (a simulant, for our purpose, of muscle tissue). If we assume that the resisting force is of the viscous kind, that is, proportional to the i antoneous speed, V, then we can write Newton's second law as

$$M\ddot{X} = -KAV \text{ (the resisting force)} \ldots \tag{1}$$

where M is the projectile mass; X is position (the double dot indicates differentiation twice with respect to time, t); A, cross-sectional area of the missile along the trajectory; V, speed (or $\dot{X}$); and K, a dimensional constant.

If when X = 0 the initial striking speed of the missile is V_0 the integration of (1) leads to

$$X(t) = V_0 \frac{m}{K} [1 - e^{-\frac{K}{m}t}] \ldots \tag{2}$$

where $m = \frac{M}{A}$.

The final depth of penetration, P can be found from (2) by letting $t \to \infty$

$$P = \frac{MV_0}{KA} \ldots \tag{3}$$

Relation (3) indicates that penetration is linearly proportional to momentum divided by presented area. While not agreeing with this prediction of linearity, available experimental data do indicate that, in general, penetration is a function of momentum per unit area. Although our problem is in trying to predict the maximum speed at which the missile will fail to penetrate at all we thought that, as a first guess, we ought to try to scale our experimental data in accord with equation (3).*

---

* *The term ballistic limit is occasionally used to indicate the speed at which half the missiles striking the target will perforate (go completely through).*

The Experiments

Steel cubes, spheres and cylinders of weights up to 15 grams and velocities up to 2000 meters per second were fired into isolated skin (both human and goat) and into soldiers' combat clothing (six layers of heavy winter uniform); clothing was included in our study because it represents a bound (at least in the winter) of improved protection of a soldier. Characteristics of the clothing and tissue are given in Table 1. Special smooth-bored guns were constructed for the experiments. Suitable counter chronographs were used to determine striking velocities.

Since we were dealing with unstabilized missiles, the missile usually tumbled in flight prior to striking the target. Thus, the value of A is an average. For missiles with convex surfaces (no re-entry surfaces), the average presented area is one-fourth (1/4) the surface area.[2]

Results

We were gratified to find that the maximum speed, V_{50}, at which a fragment would just perforate either skin or clothing could be expressed by

$$V_{50} = K \frac{A}{M} + b \tag{4}$$

No significant differences were noted between human and goat skin and data for the two were combined. The results are plotted in Figure 1. The points represent average values, the lines are least square fits. As many as 30 datum points were used for each average value.

Least square vrlues for K and b are as follows:

	K	b (m/sec)
Clothing	261	73.5
Skin	125	22.0

M is measured in grams and V is given in meters/sec.

Some representative values of V_{50} for steel spheres, from the curves, are:

M gm	V_{50} Uniform	Skin
1	154	60
2	137	52
10	111	40

TABLE 1

DESCRIPTION OF MATERIALS

COMBAT WINTER CLOTHING - 6 LAYER

A. Sateen - 9 oz/sq yd

B. Oxford - 5 oz/sq yd

C. Frieze (mohair, wook, cotton) - 16 oz/sq yd

D. Ripstop (fortisan + rayon) - 4 oz/sq yd

E. Shirting (85% wool, 15% cotton) - 16 oz/sq yd

F. Underwear (50% wool, 50% cotton) - 12 oz/sq yd

ISOLATED HUMAN SKIN

A. Removed from cadaver thigh

B. Average thickness - 0.3 cm

ISOLATED GOAT SKIN

A. Removed from goat thigh, hair removed

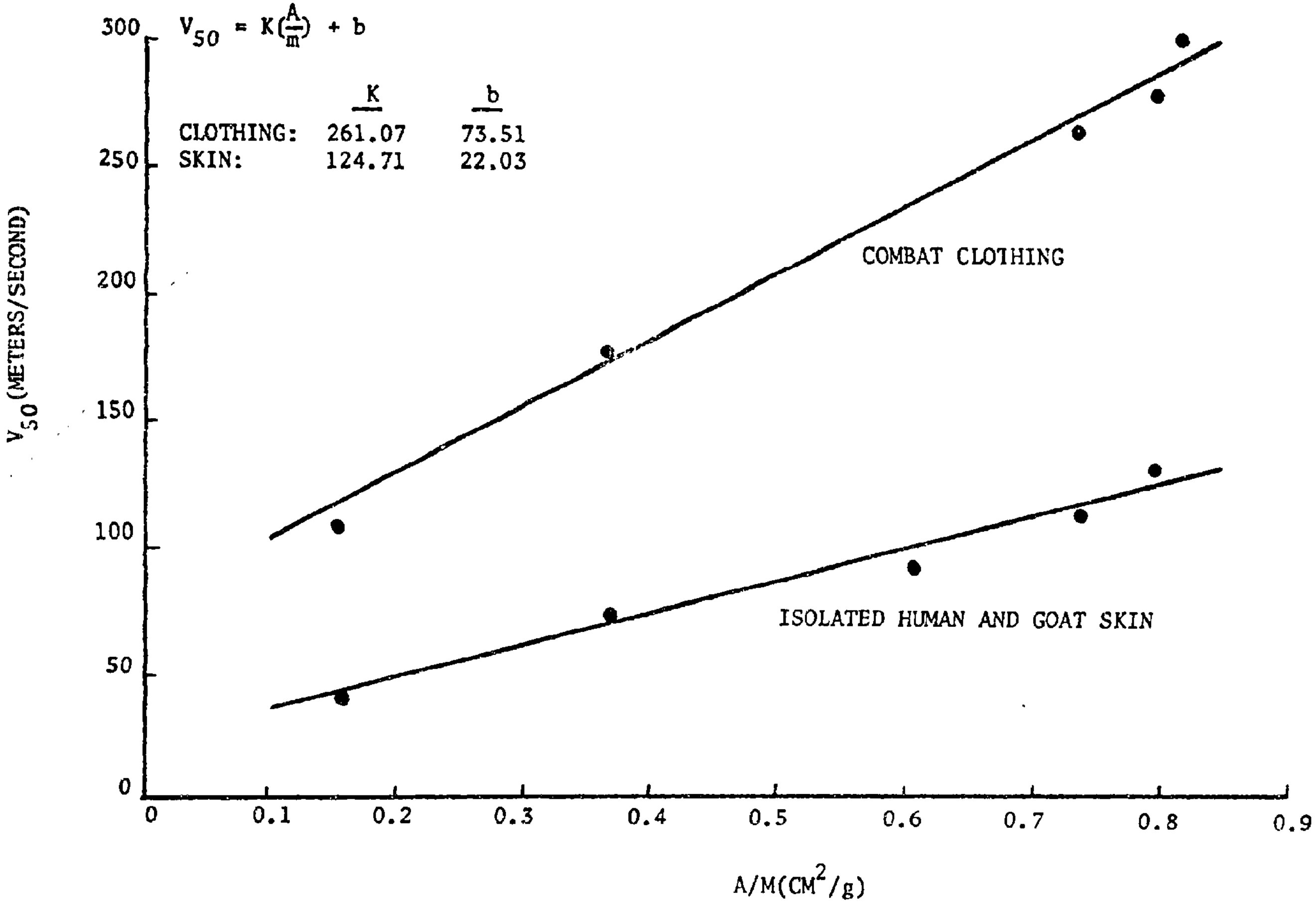
B. Average thickness - 0.3 cm

FIGURE 1

BALLISTIC LIMIT (V_{50}) VERSUS FRAGMENT AREA/MASS

FOR

COMBAT WINTER CLOTHING AND ISOLATED HUMAN AND GOAT SKIN



References

1. Numerous reports of the Biophysics Laboratory, Edgewood Arsenal, Maryland.

2. SCHWARZSCHILD, Martin and R. G. SACHS. 1943. Properties of Bomb Fragements. USABRL REPORT NO. 347.

FRAGMENT HAZARD CRITERIA

by

D. I. Feinstein

The following discussion relates to a review of data pertaining to the effects of fragments upon the human body and the rational development of a casualty criteria developed from this data. Finally the developed casualty criteria has been related to other existing criteria.

The effects of fragments on biological tissues were reviewed using available experimental evidence and including superficial, incapacitating, and near lethal categories of injury. Missiles consisted of glass, bullets, balls, and blunt objects. The parts of the body used were: skin, lower abdomen, thorax, limbs and skull.

Dose functions, consisting of missile mass, M, and velocity, V, were developed as a method to integrate evidence concerning casualty effects under differing terminal conditions. Here, extensive use of extrapolated and interpolated experimental results were utilized. Momentum MV, energy MV^2, and energy times velocity square MV^4, depending upon the mechanism of injury, were assigned as the dose functions. These three functions, applied to injuries, were primarily in the nature of: (1) impulse loading for momentum; (2) crushing or tearing for energy; and (3) cutting or penetrating for energy.

This method made possible digital computation of probable biological effects in a diverse missile environment interrelating the various kinds of experimental evidence available. The values estimated and formulas proposed served as a hypothesis for further experimental validation. Application of these formulas will reveal which mechanism of injury and missile environments are of greatest importance. How critical the assumptions can be revealed by variations of these parameters.

Four groups of data based upon experiments were considered: penetration of the lower abdomen of dogs by glass (Ref. 1), effects of missiles on human cadavers (Ref. 2), data on skull fracture (Ref. 3), and effects of missile impact on the chest (Ref. 4). There were considerable differences in the scope of these data groups and in the availability of raw observations for independent estimations of parameters. The probability of penetration or laceration by glass was related to the mass and velocity of the missile by MV^4. This statistic was then used to attempt to consistently account for other biological effects of missiles

regarding injuries which primarily involve penetrating wounds. Some results concerning larger missiles, with biological effects primarily involving bones, did not fit this relationship. The data on skull fracture also proved the necessity for using another statistic. It was found that mass times velocity squared satisfied the requirements to explain crushing or tearing wounds such as most bone injuries or passage through regions of tissue. These injuries could be incurred with or without penetration of intervening tissues as in the case of skull fracture, bone breakage, or rib fracture complicated by internal lacerations. When the tissue has been penetrated, energy is the determining factor for estimating the probability of complete passage through a limb. It was found that even these two statistics did not correlate well for unilateral lung hemorrhage and simple rib fractures. It appeared from the data available that mass times velocity alone could be used to predict the occurrence of these injuries.

Table 1 summarizes the mass-velocity relationships obtained for the data reviewed. The dose relationship column indicates the criteria employed to relate biological response with missile characteristics at the time of impact. The last three columns in Table 1 present the value of the missile-velocity dose for 10, 50 and 90 percent probability of the specific effect occurring. For optimistic and pessimistic estimates of the 50 percent probability values indicated in Table 1, 70 and 140 percent of the values provided are suggested, based on the uncertainty of the data for the MV^4 doses, and 80 and 125 percent for the MV and MV^2 doses. Different probability values can be determined from Table 1 by the following relation

$$S^2 = \left(\frac{\log P90 - \log P50}{1.282}\right)^2$$

$$P_i\left\{x\right\} = \frac{1}{2\pi S}\int_{-\infty}^{x} e^{-(t-\log P(50)^2/2S^2)}dt$$

where P_i is the probability of the effect occurring.

Figure 1 is a graph of 50 percent probability thresholds for each effect in Table 1. The curves of Fig. 1 are obtained by applying the specific relationship of Table 1 between M and V to obtain the 50 percent probability of the effect occurring. For example, for rib fracture (MV relationship) the 50 percent probability is 31 x 10^3 gm ft/sec. Therefore, for a 1,000 gm mass, the missile velocity must be about 31 fps for 50 percent probability of rib fracture. If the mass of the missile is 100 gm, the velocity must be 310 fps. In a similar manner, the 50 percent values of the other effects at various velocities and ranges were determined.

Table 1

SUMMARY OF BIOLOGICAL EFFECTS OF MISSILE DATA

No.	Effect	Part of Body Tested	Ty of Missile Used	Part of * Body for Application	Target Area % Body	Target Area ft^2	Dose Relationship	Units	Probability of Effect Occurring, percent: 10 (Dose Required)	50 (Dose Required)	90* (Dose Required)	Severity
1	Laceration	Skin	Glass	General	100.0	4.20	MV^4	gm $\frac{ft^4}{sec^4}$	0.108×10^9	0.902×10^9	7.50×10^9	Superficial
2	Penetration	Abdomen	Glass	Abdomen and limbs	25.0	1.01	MV^4	gm $\frac{ft^4}{sec^4}$	0.569×10^9	3.83×10^9	25.9×10^9	Incapacitating
3	Laceration	Skin	Spherical Bullets	General	100.0	4.20	MV^4	gm $\frac{ft^4}{sec^4}$	4×10^9	11×10^9	30×10^9	Superficial
4	Penetration	Limb	Spherical Bullets	Abdomen (lower) and limbs	25.0	1.01	MV^4	gm $\frac{ft^4}{sec^4}$	9×10^9	24×10^9	64×10^9	Incapacitating
5	Bilateral Hemorrhage	Lung	Balls	Thorax	15.5	0.65	MV^4	gm $\frac{ft^4}{sec^4}$	65×10^9	175×10^9	475×10^9	Near Lethal
6	Fatality within 1 hr	Thorax	Balls	General	43.0	1.81	MV^4	gm $\frac{ft^4}{sec^4}$	225×10^9	625×10^9	1625×10^9	Lethal
7	Fracture	Skull	Blunt Objects	Head	8.0	0.33	MV^2	gm $\frac{ft^2}{sec^2}$	0.974×10^6	1.37×10^6	1.93×10^6	Near Lethal
8	Bone Abrasion and Cracking	Limbs	Spherical Bullets	Not including ribs	35.0	1.47	MV^2	gm $\frac{ft^2}{sec^2}$	0.6×10^6	0.9×10^6	1.3×10^6	Incapacitating
9	Passage	Thigh	Spherical Bullets	Abdomen and limbs	25.0	1.01	MV^2	gm $\frac{ft^2}{sec^2}$	1.4×10^6	2.0×10^6	2.8×10^6	Near Lethal
10	Fractures Large Bones	Limbs	Bullets	Not including ribs	35.0	1.47	MV^2	gm $\frac{ft^2}{sec^2}$	2.3×10^6	3.4×10^6	5.0×10^6	Near Lethal
11	Internal Lacerations on Fractured Ribs	Thorax	Balls	Thorax	15.5	0.65	MV^2	gm $\frac{ft^2}{sec^2}$	3.1×10^6	4.5×10^6	6.6×10^6	Incapacitating
12	Unilateral Hemorrhage	Lung	Balls	Thorax	15.5	0.65	MV	gm $\frac{ft}{sec}$	16×10^3	22×10^3	29×10^3	Superficial
13	Rib Fractures	Thorax	Balls	Thorax	15.5	0.65	MV	gm $\frac{ft}{sec}$	24×10^3	31×10^3	40×10^3	Superficial

* Thus for a glass missile imparting skin with 7.5×10^9 gm ft^4/sec^4 the probability of laceration occurring is 90 percent.

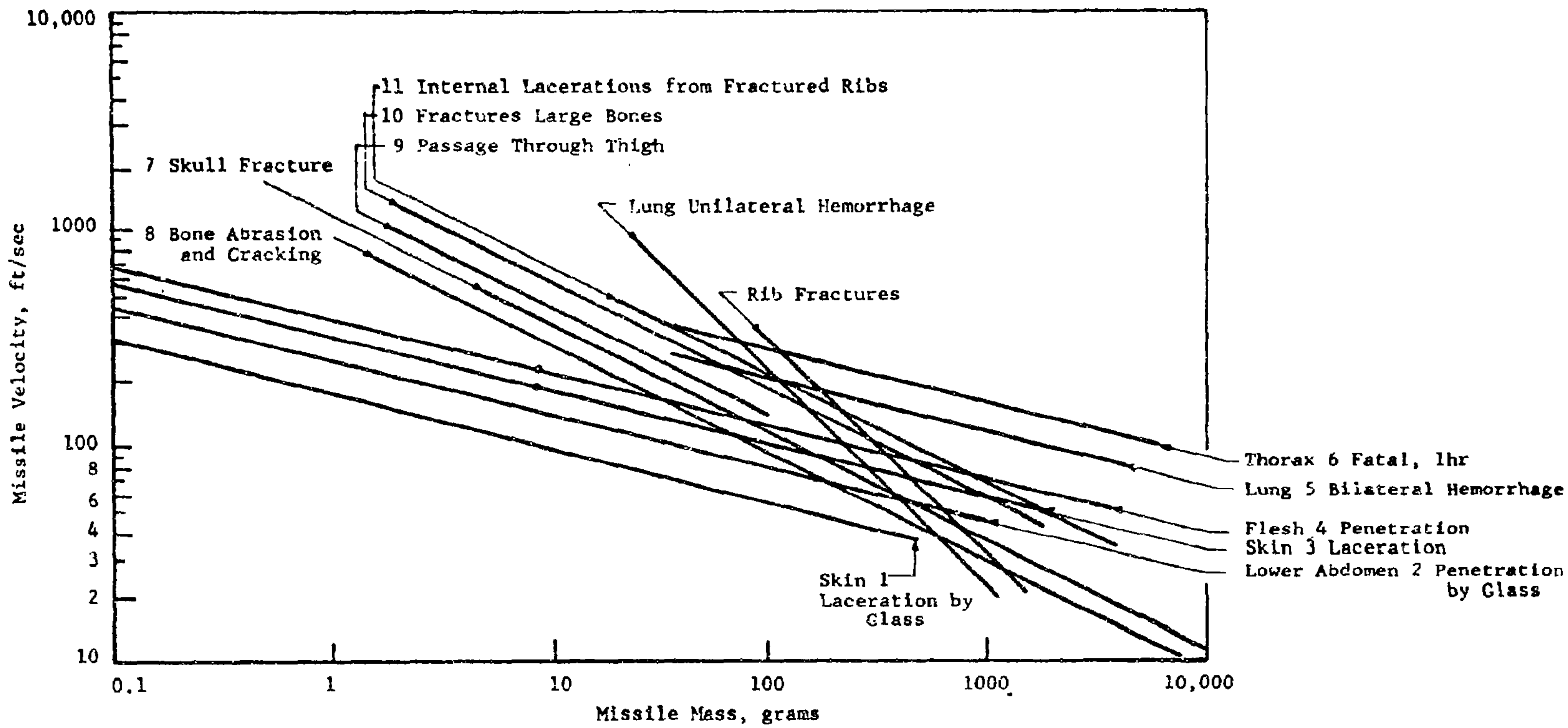


Fig. 1 VARIOUS BIOLOGICAL EFFECTS OF MISSILES

The goal here was to isolate casualty criteria which could be used to analyze hazards due to fragments. A series of functions have been developed relating missile characteristics to probability of injury. The severity of injuries and associated probability of mortality based on severity have also been estimated. However, even at this stage functions are of limited value. Therefore, the effects of severity and probability of occurrence for each effect have been combined, averaged and extrapolated as necessary to obtain one continuous relationship covering the complete range of missile masses and velocities which might be of interest where data were available. For example, in Case 1 of Table 1 the effect of penetrating glass is classified as a superficial wound and is estimated at 10 percent mortality. The probability of a glass fragment missile mass-velocity combination producing mortality can subsequently be determined by multiplying the probability of its producing the effect by the mortality probability. If the probability of producing a superficial wound is 10 percent, then the probability of producing mortality from the same missile mass-velocity combination is only 1 percent. In a similar manner, each of the effect relationships was changed to mortality and plotted on one graph for each applicable body region (head, thorax, abdomen and limbs). Those relations marked "general" were applied to each graph, while those indicated for a specific region were only used when that region applied. An example of the former is the category of skin laceration, which can be used for each region. Three graphs resulted similar to Fig. 1 with almost as many lines. Effects requiring the least velocity were selected in each mass region, and then various relations were averaged visually (at this point it hardly seemed worth the effort to do more).

Table 2 provides an estimate of total body projected area as well as vulnerable areas of various body regions. This date was useful later when complete consideration of fragment coverage areas, fragment characteristics and body areas were used in making casualty descriptions. However, it was used in making qualitative estimates of mortality based on the injuries reported in the data summarized in Table 1. The type and size of missiles has a definite effect on vulnerable areas. Future research on missile casualties might consider some of these effects when reporting data.

Table 2

BODY TARGET AND VULNERABLE AREAS (REF. 5 AND 6)

Region	Area ft^2	% of Total	Vulnerable Area: Area ft^2	% of Region	% of Body
Head and Neck	0.5	12	0.15	30	3.5
Thorax	0.67	16	0.65	97	15.5
Abdomen	0.46	11	0.45	97	10.5
Upper Limbs	0.92	22	0.19	20	4.5
Lower Limbs	1.65	39	0.38	23	9.0

Kneeling presents approx. 55% of field projected area
Sidewise presents approx. 45-50% of field projected area
End of prone presents 25% of field projected area.

Three sets of curves emerged, one (each) for MV, MV^2 and MV^4, and separate ones for 10, 50 and 90 percent mortality probability. These were made continuous by using the lowest velocity curves for each mass and cutting off the curves at the intersection points. The results are illustrated by Fig. 2. As an afterthought, the casualty criteria employed in World War II was plotted on each of these figures, and the similarity was gratifying. It is highly recommended that future research in the areas of casualty criteria and mortality be aimed at covering the full range of mass and velocity of interest to explosive safety problems, and further that an attempt be made to verify the estimates made in conducting this study.

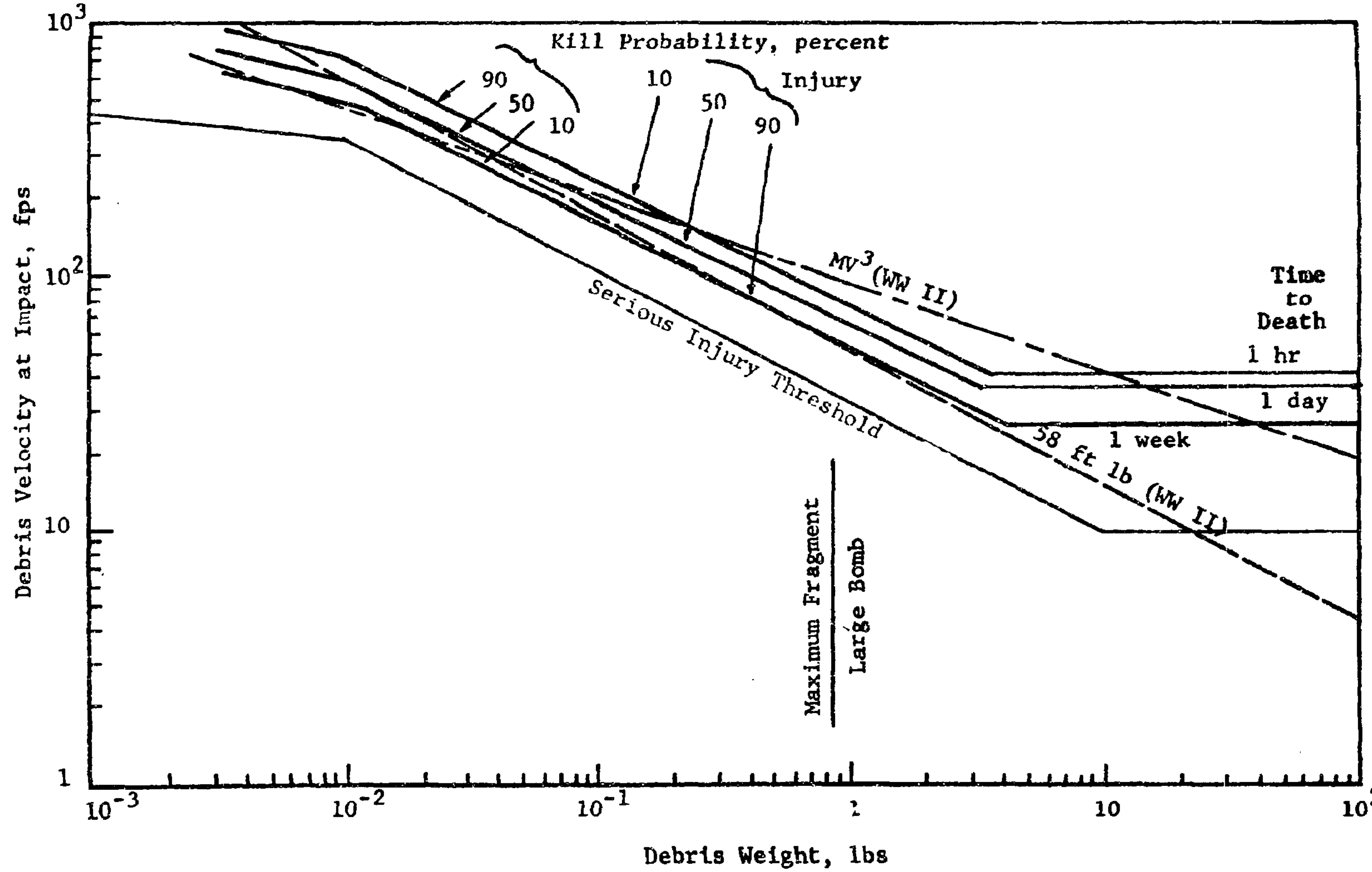


Fig. 2 KILL PROBABILITY FROM DEBRIS IMPACTS (Head)

References

1. Bowen, G. I., et al., Biological Effects of Blast from Bombs, AECU-3350, June 18, 1956.

2. Journee Rev. D'Arillerie, May 1907.

3. Gurdjian, E. S., American J. Surg., 78:736-742, 1949.

4. Richmond, D. R., Bowen, G. I. and White, Biological Effects of Blast and Shock, Tech. Progress Report, Lovelace Foundation, Albuquerque, N. M., Contract No. DA-49-146-XZ-055, April, 1966.

RESIDENTIAL STRUCTURAL DAMAGE

by

Chuck Wilton
URS Research Company

INTRODUCTION

During the past several years, URS has been investigating the structural damage sustained by residential houses when exposed to airblast. The purpose of these studies has been to obtain a data base for prediction of casualties and damage resulting from accidental explosions of large quantity of explosives and check the validity of quantity distance criteria. Field tests using large quantities of explosives have generally exposed residential houses to relatively low overpressures (less than 3 psi) where the primary result has been minor structural damage and the primary casualty producing items have been window glass fragments, window casings, and doors.

With the exception of a small amount obtained on nuclear tests, very little field test data is available on houses exposed to higher overpressures in which failing structural elements could cause casualties. In addition, because most of the recent field testing has utilized a two-story, wood frame house there is very little field test data on building materials other than wood.

In an attempt to fill these information gaps without resorting to expensive field testing, the Office of Civil Defense has been sponsoring a program using the URS Shock Tunnel. In this program, failure tests have been conducted on full-scale, interior, and exterior wall panels of a variety of materials, including brick, cinderblock, wood siding, concrete, sheetrock, and clay tile. (Only brick and sheetrock walls will be discussed here.)

THE URS SHOCK TUNNEL

The shock tunnel has been discussed in previous seminars; only a brief description will be given here. It uses the tunnel complex and casemate area of a former coast defense gun emplacement complex (see Fig. 1). In a 63-ft long section of the tunnel complex, URS installed an 8-ft diameter, steel cylinder open at one end. As shown in Fig. 2, the cylinder is held in place within the tunnel with polyurethane foam to absorb thrust and provide some stability against cylinder collapse. Shock waves are formed by the detonation of primacord strands in the steel cylinder. Some 100 ft further down the

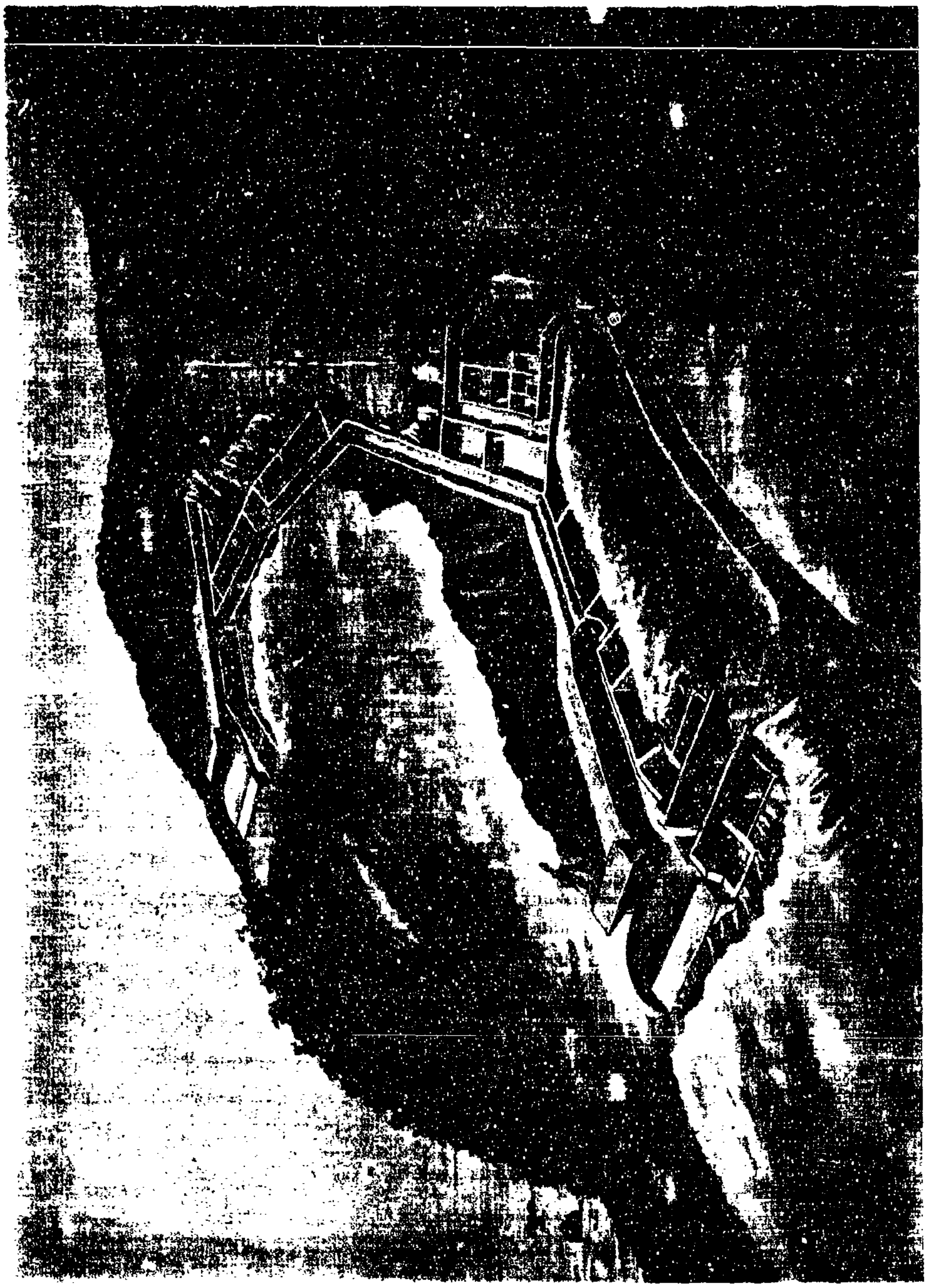


Figure 1. Cutaway View of the URS Shock Tunnel Complex.

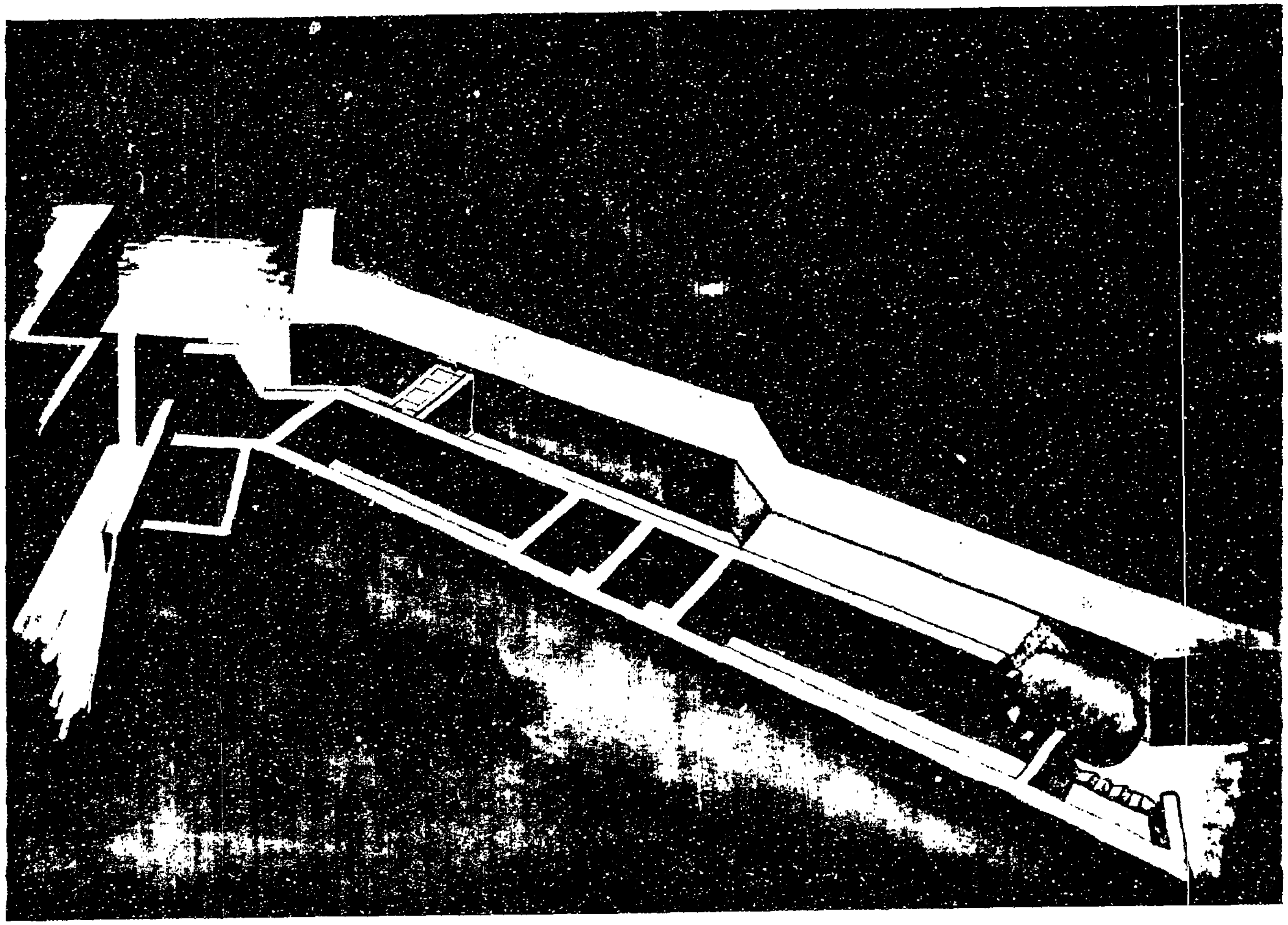


Figure 2. Sketch Showing Mounting of the Steel Cylinder and a Test Wall in Place in the URS Shock Tunnel.

tunnel, in an area $8\frac{1}{2}$ ft high and 12 ft wide, a test section has been installed in which walls can be mounted, and pressure and wall loading measurements made. The general characteristics of the mounting system are shown in Fig. 3 which shows a test wall in a frame, and the massive plate girders on which the wall is mounted and with which wall loading measurements are made.

TYPICAL TEST RESULTS

Most tests have been made on non-reinforced brick walls. On 8-in. thick simple beam supported walls (i.e., walls supported on top and bottom only) incident overpressures of as little as 1.5 psi (peak reflected pressures of about 3 psi) are adequate to cause wall failure. At this level, the wall initially breaks up into two or three large pieces (failure planes are generally horizontal, parallel to the supports) which subsequently break still farther upon impact with the floor. The pieces are still quite large, with the debris generally restricted to an area within 20 ft from the original wall location (Fig. 4).

A similar 8-in. thick wall supported as a simple plate (on all four sides) is slightly stronger; 1.5 psi incident (3.0 psi peak reflected) pressure is adequate to crack the wall but not to eject any debris (Fig. 5). A slightly higher pressure (3.5 psi peak reflected) was just sufficient to knock a section out of the wall but not to cause its total collapse (Fig. 6).

At higher overpressures - in the 7-10 psi peak reflected region - wall failure is massive and fragments which may be of large size are ejected with sufficient velocity to cause significant casualties. From an 8 in. simple beam supported wall, fragments ranging in weight from 16 lb to 300 lb were found against the back wall, 77 ft from the original wall location, numerous fragments weighing more than 100 lb were found within 50 ft, and a 400 lb fragment was found at 34 ft from the original wall location (Fig. 7).

Simple plate supported walls which, as noted above, are slightly stronger than simple beam supported walls had most of their debris within 50 ft of the wall although on one test a 200 lb fragment was found at 50 ft, and another at 40 ft from the original wall location (Fig. 8).

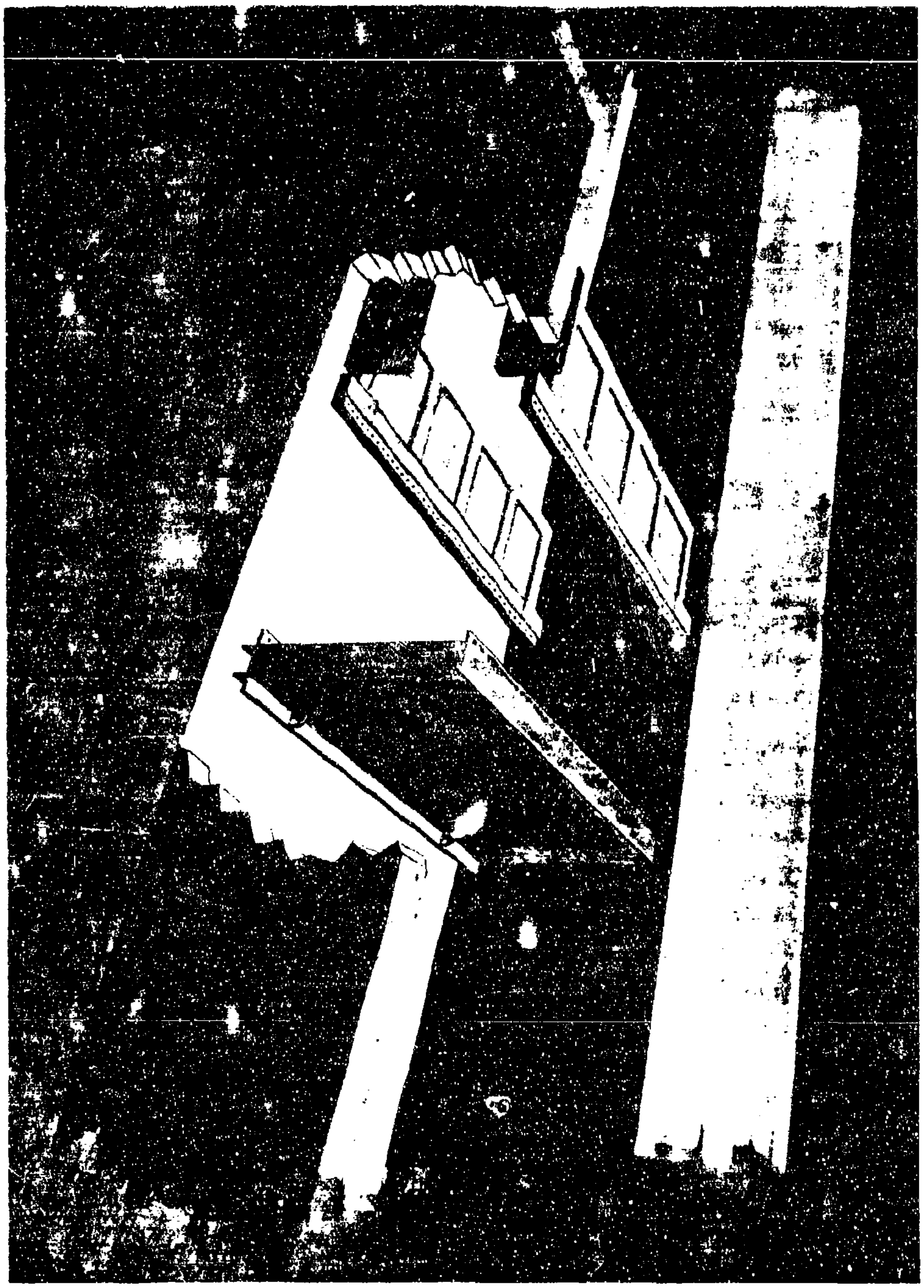


Figure 3. Sketch Showing How a Simple Beam Wall is Mounted.

Figure 4. Debris from a Simple Beam Wall, Peak Overpressure = 3 psi.

Figure 5. Simple Plate Wall, Overpressure = 3.0 psi

Figure 6. Simple Plate Wall, Overpressure = 3.5 psi

Figure 7. Debris from a Simple Beam Wall, Peak Overpressure ≃ 10 psi.

Figure 8. Debris from a Simple Plate Wall, Peak Overpressure ≃ 9.3 psi

At still higher overpressures (~ 15 psi peak reflected pressure) many large fragments were found along the back wall. In one test a 255 lb fragment and a 530 lb fragment was about 55 ft from the original wall location. A total of fragments with a total weight of 5,200 lb were found beyond the 40 ft mark. Figure 9 shows debris from a simple plate wall.

Sheetrock walls, of course, fail at considerably lower overpressures than brick walls. Relatively large pieces of sheetrock and 2 x 4 studs are formed, and most were found along the back wall, 77 ft from the original wall location. Figure 10 shows the debris from a test in which the sheetrock wall was located behind a non-failing wall in which there was a doorway. Peak reflected pressure at the location of the sheetrock wall was about 5.4 psi.

Figure 9. Debris from a Simple Plate Wall, Peak Overpressure ≃ 16.3 psi

Figure 10. Debris from a Sheetrock Wall located behind a Non-Failing Wall with a Doorway. Peak Overpressure at the Sheetrock Wall Location ≃ 5.4 psi.

IDENTIFICATION STANDARD
FOR
SPACE SYSTEMS EXPLOSIVE DEVICES

Mr. Paul D. Davis
NASA Safety Office
Washington, D.C.

PRECEDING PAGE BLANK

IDENTIFICATION STANDARD
FOR
SPACE SYSTEMS EXPLOSIVE DEVICES

Three years ago a colleague of mine from NASA stood before a similar group at the tenth annual Explosive Safety Seminar in Louisville and discussed the requirement for a government/industry uniform color code standard for aerospace explosive devices. During the course of his talk, he showed this slide of the various color systems being used on different programs at that time. I would like to show you now how far we have progressed, what is being used today, and how it has been simplified.

During the course of my presentation today, I would briefly like to touch upon four points.

1. Why a uniform Color Code Standard?
2. Why existing standards are not adequate.
3. Problems in color coding.
4. A proposed identification standard.

You might ask, and I have been asked quite frequently in the past few months, why we even need a color code system for aerospace explosive devices. NASA alone is concerned with three major launch sites at the present time. Kennedy Space Center and the Air Force's Eastern Test Range at Cape Kennedy, Florida, The Air Force's Western Test Range at Vandenburg Air Force Base, California and NASA's Wallops Station, Wallops Island, Virginia. There are currently at Cape Kennedy approximately twenty different programs utilizing explosive

devices. The devices are presently being stored and maintained by a single contractor. They are presently storing in the neighborhood of eight hundred (800) different devices for a total of approximately fifty-five thousand items. As you can see, with the multitude of color schemes being used, the colors have become meaningless. What is used for a "live" device in one program would indicate a "simulator" or "inert" device on another. Contractors lucky enough to have two programs frequently find themselves supplying "live" devices coded "red" for one program and "live" devices coded "green" for another. The ultimate was recently reached when a contractor was fortunate enough to have a contract with two different NASA centers on the same program. One center wanted its explosive devices coded "blue" for "live" and "red" for "inert". The other center desired "red" for "live" and "blue" for "inert". The launch center was the one who ended up with this hodge podge of colors and has the task of trying to make sense of the confusion and hazard that has been created.

I feel some of the problems in this areas have been created by trying to color code the quality of an item rather than just its hazardous nature. When we discuss the hazards associated with aerospace explosive devices, we usually speak of two types of hazards. First, there is the inherent hazard of an explosive device to the personnel who must load it, check it out, test it, store it and finally install it for flight or final test. This hazard lends itself easily to identification by color. What color? Any color as long as it's uniform throughout the aerospace industry, and is known for what it is.

The other hazard to which we often refer, and erroneously I feel, is the hazard in installing an item of unknown quality, be it inert, off nominal load, or dud for flight, rather than a "live" qualified item. Now, how do you identify "quality" by color. You don't! This is much much better maintained by records and data just as is presently being accomplished for a piece of hardware or electronic gear. These methods are well known and used throughout the industry.

I would like to give my observations as to Why Existing Standards Are Not Adequate:

The explosive color coding as expressed for explosives in MIL STD 709A pertain almost solely to ammunition. It (MIL-STD-709A) does mention Guided Missiles in the first paragraph, but does not refer to them again. It does not take into consideration problems associated with space vehicles such as thermal properties to which an item might be subjected, contamination of a clean system with paint, optical tracking requirements for rocket motors, and others. The standard specifically points out that any color used in the standard cannot be used for completely "inert" items.

The Air Force recognized this area as a problem, and issued two documents in an attempt to cover the situation. These were T.O. 11A-1-53 "Identification of Empty and Inert Loaded Explosives Items and Components for Display and Training Purposes" issued in March 1969, and AF/SSD Exhibit 61-70A "Color and Marking Criteria for Large Solid Motors and Ordnance Systems" in November 1962. These two documents take the first step in covering the void.

What Are The Problems in Color Coding Aerospace Explosive Devices?

These are some unique problems associated with color coding aerospace explosive devices which I referred to and would like to now explain. Seventy five percent of all devices used on space vehicles are too small to paint, as you can see from the typical items on this slide. The electrical connector can't be painted as this could possibly contaminate the mating connector. The output end can't be painted as this could possibly contaminate the system it is intended to be used in. There are some items which must be a certain color for thermal balance, and then their are or (may be) certain optical tracking requirements which must be met for solid propellant rockets. As you can see, the list could be endless depending on the requirements and mission of a particular vehicle. What can be done?

A Proposed Standard

A year ago I was given the responsibility by the NASA Director of Safety to prepare an agency wide explosive color code standard. I had a series of conferences with knowledgeable individuals on the subject from the Department of Defense, private industry, and within NASA. A preliminary draft was written and circulated to all NASA centers in December for review and comment. The comments received in March were very interesting. They revealed we didn't need just one standard. We would require fourteen. This broke down as follows: Three different ones for one Launch Site, one for Headquarters and one each for the other ten centers. Everyone

thought a agency wide color code standard was a great idea, and if we would only use his system it would be perfect.

Seriously, we received some excellent comments. But we recognized right away some major problem areas as well as the fact that someone would have to change regardless of what system was finally agreed upon. Some of the areas which became apparent are:

a. Items should be color coded for ground handling and check-out only. As you can see from these slides, once an item is installed, it tends to lose its identity. They are not easily accessable or recognizable.

b. A large precentage of items are inserted into systems which have a high cleanliness requirement or are incompatible with paint.

c. Most engineers originating color coding systems were unaware of the launch site's procedures and methods for handling, storage, checkout and installation of explosive devices aboard a space vehicle.

As a result of the comments received, the proposed standard was rewritten, incorporating those comments that would give us the best standard and result in a change for the fewest centers. The resulting standard has been coordinated very closely with our launch sites since they are the primary ones concerned with the end products and it is now almost ready for release. The basic concept is as follows: The primary means for identifying explosive devices and explosive simulators will be with the use of streamers.

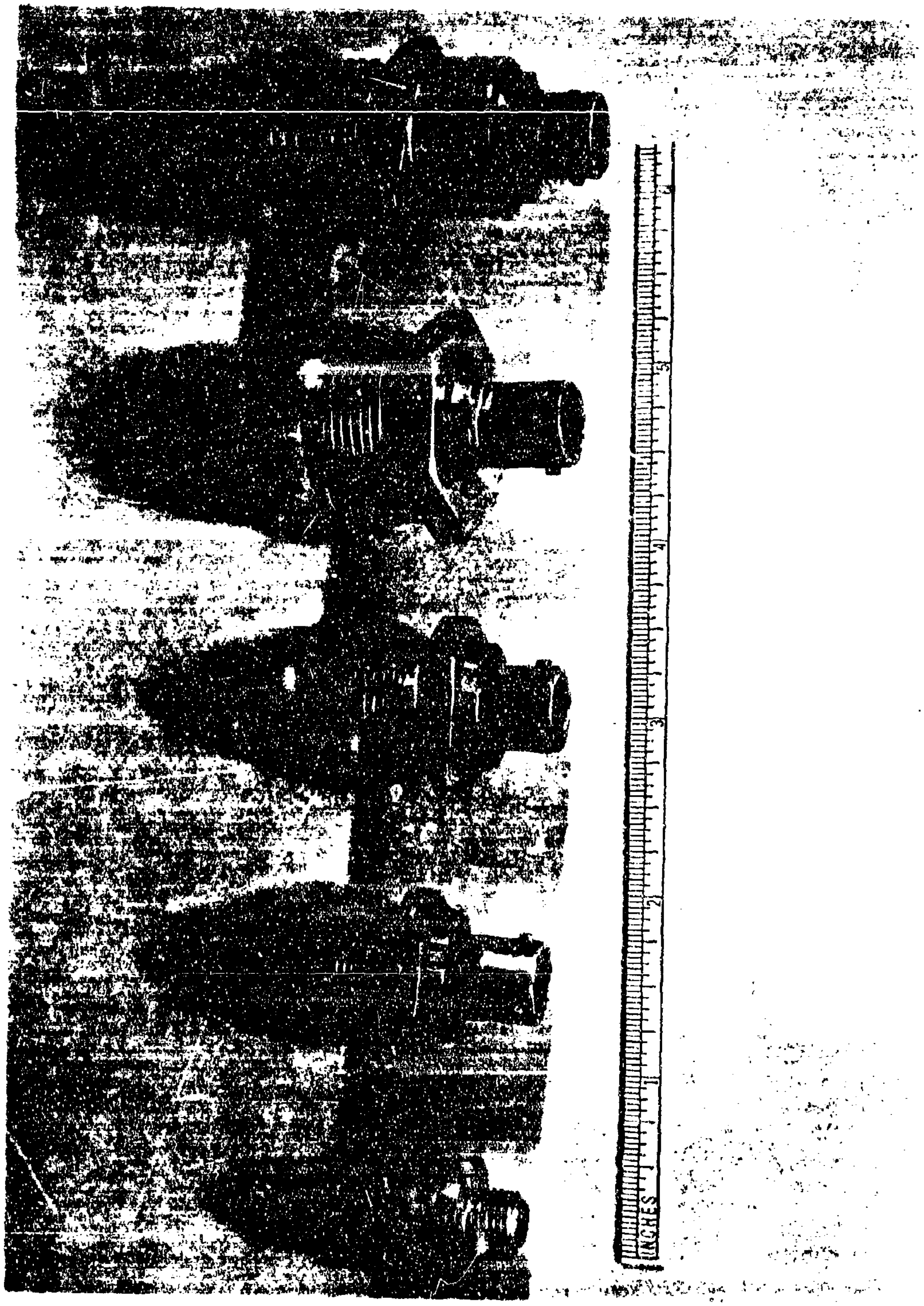
Each "live" device, and this includes off-nominal loaded devices as well, will have a red streamer attached with "live" printed on it in white letters. The color of the device shall remain the color of the base metal from which it is manufactured. In the event it must be painted for corrosion control, the color used will be "RED". Each "inert" device will have a blue streamer attached with "inert" printed on it in white letters. In addition, a blue ring or dot shall be painted on each unit, and a hole drilled through the output end. These designations shall also be used for expended items which retain enough of their shape to be used as training devices or which could be mistaken for loaded items.

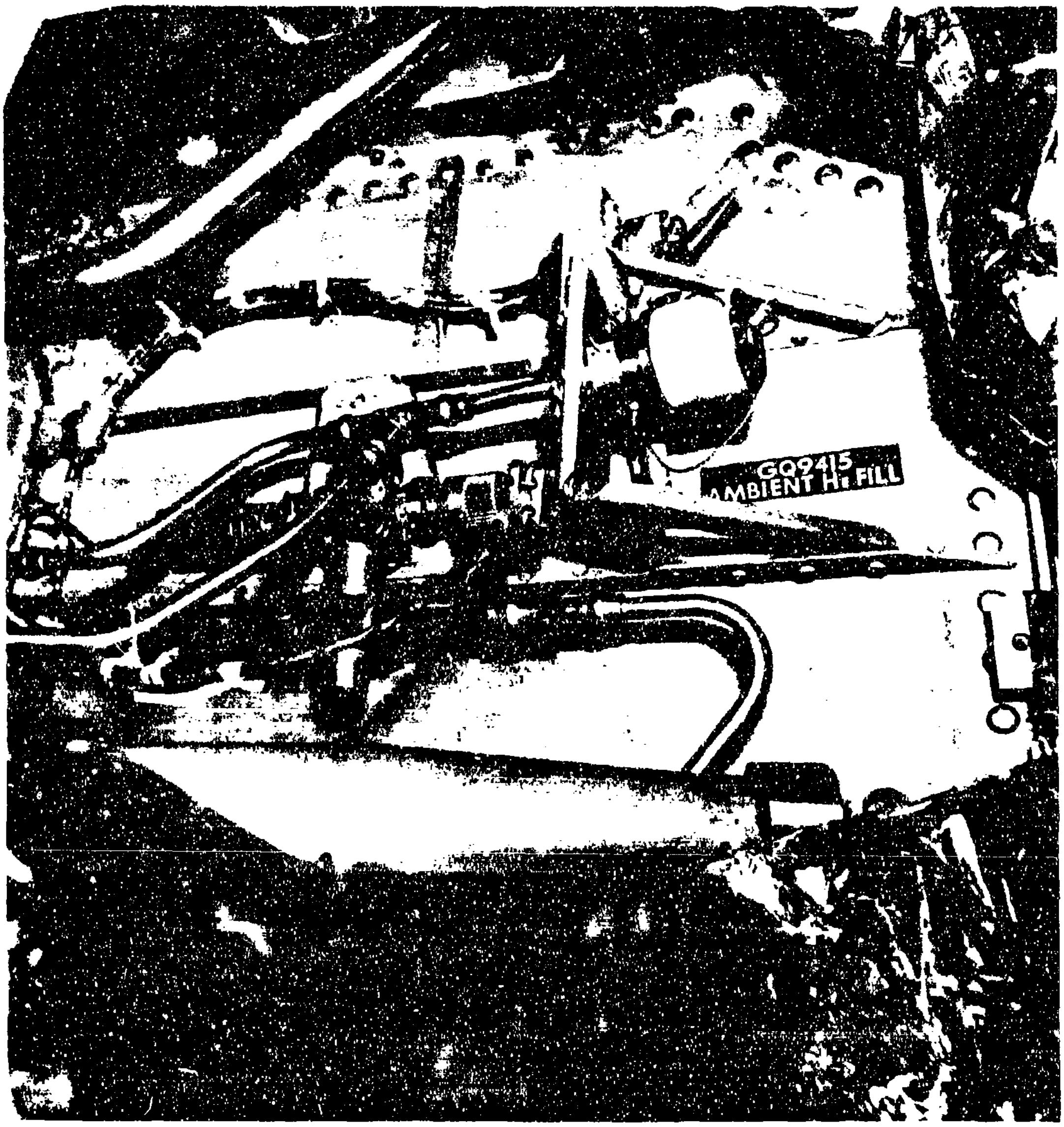
All "live" solid propellant motors shall have "live" painted on the motor case in white letters on a red background every 120° so as to be visible when the motor is in any position. All "inert" solid motors will have "inert" painted on the motor case in white letters on a blue background every 120° so as to be visible from any position. Letters shall be of sufficient size to be readily visible.

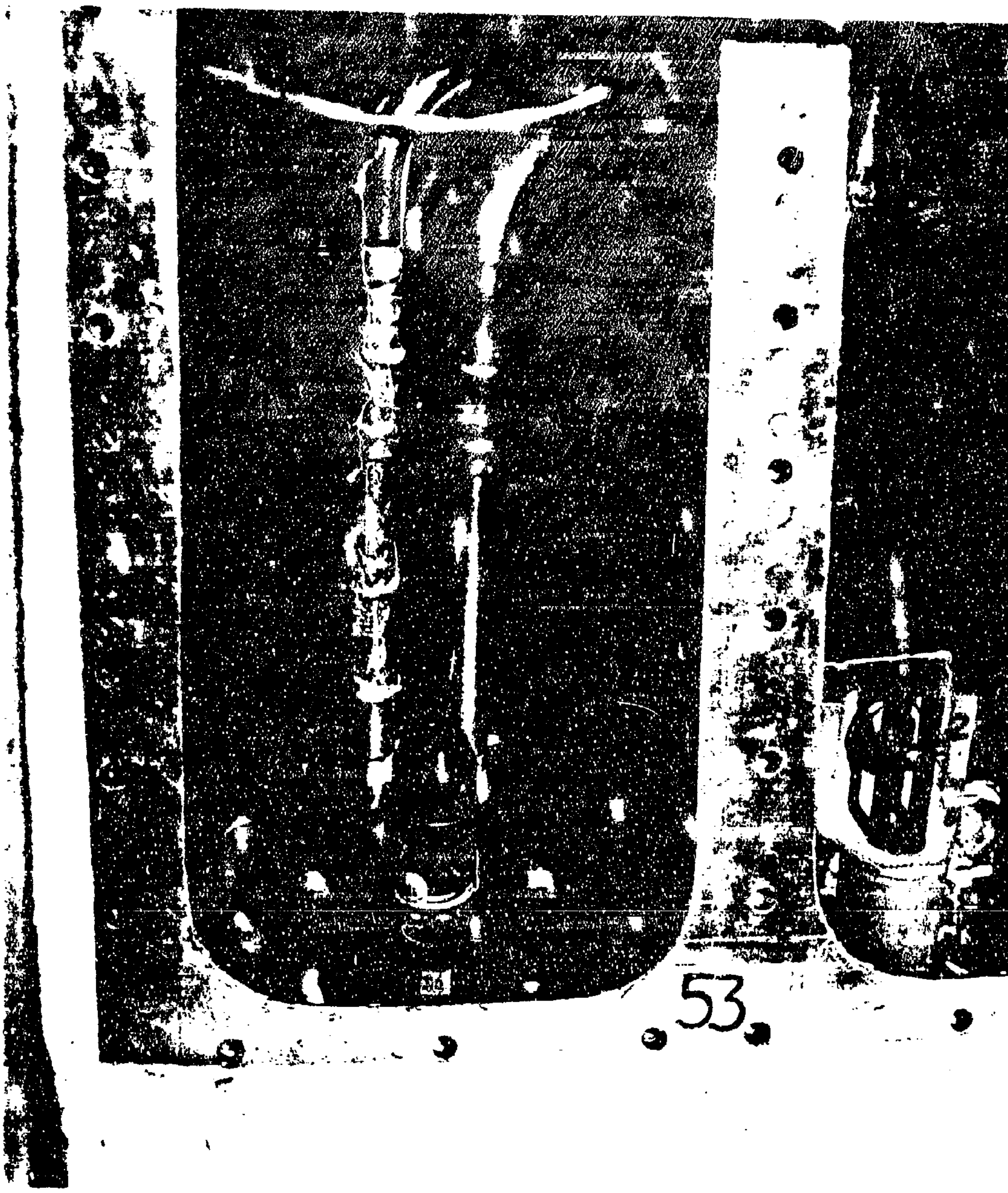
This is basically the system NASA hopes to implement in the near future. We would still like to achieve a government/industry wide standard and welcome the opportunity to sit down with anyone to try to work such a system out.

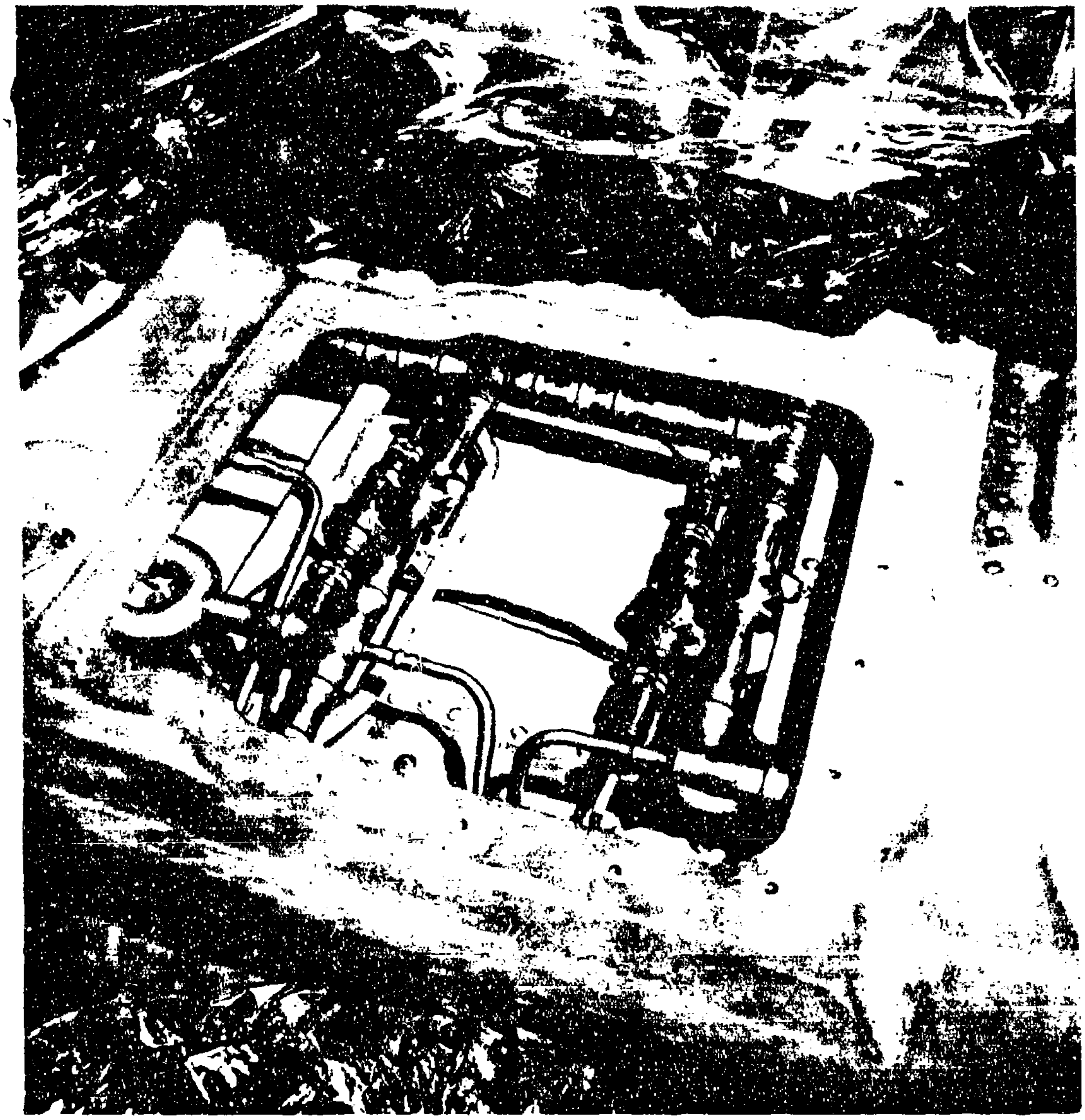
Thank you!

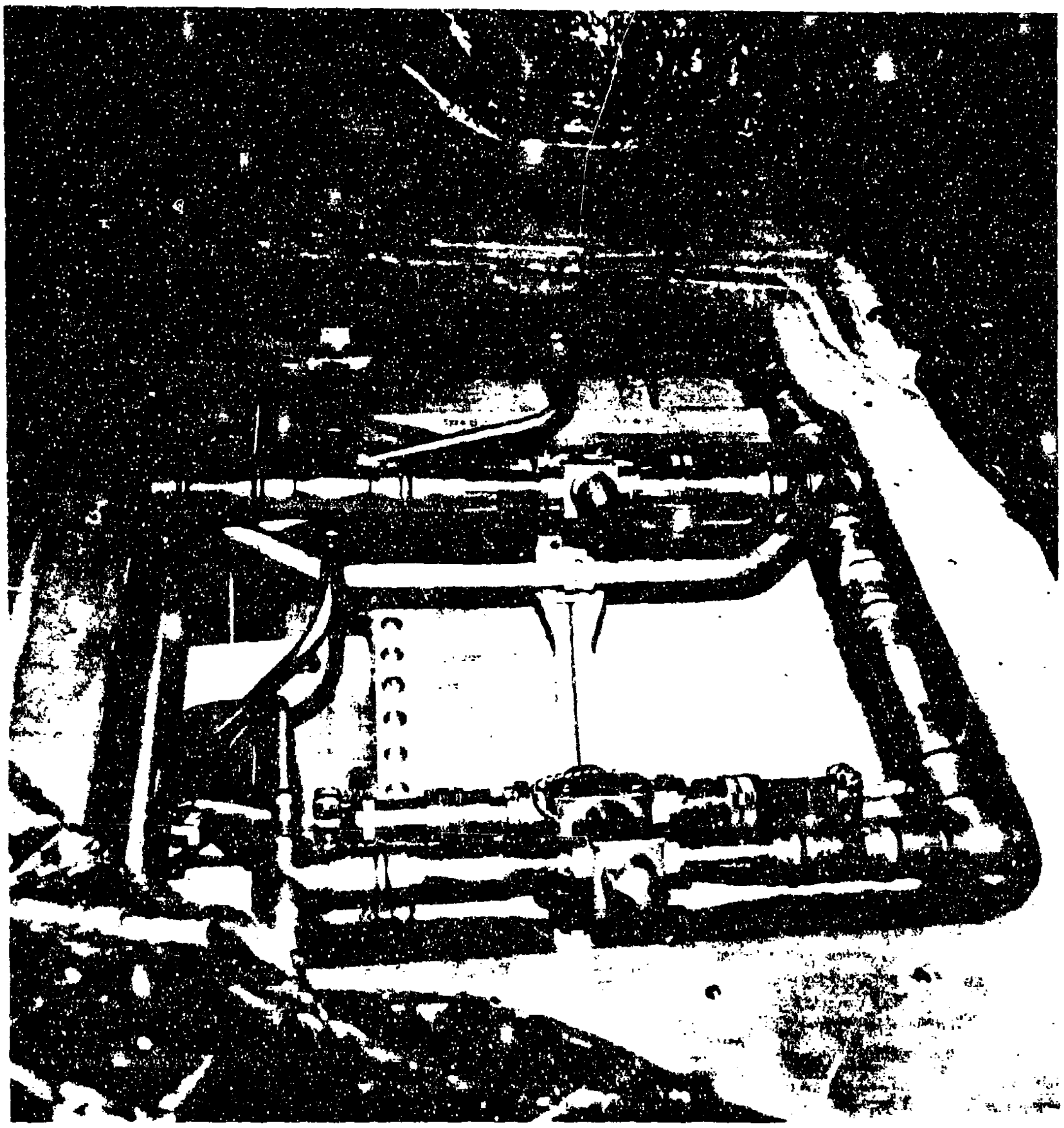
ORDNANCE COLOR CODES					
CONTR/PROJ.	INERT		LIVE		COMMENTS
ATLAS/AGENA GD/C	GREEN		RED		ATLAS
ATLAS AGENA LMSC	BLUE		RED		AGENA
THOR/AGENA DOUGLAS	NONE		SUPPLIER COLOR (NONE)		THOR
THOR AGENA LMSC	BLUE		SUPPLIER COLOR (NONE)		AGENA
ATLAS CENTAUR GD/C	GREEN		RED		ATLAS
ATLAS/CENTAUR GD/C	GREEN		RED		CENTAUR
SATURN/CHRYSLER	BRIGHT ORANGE		NONE		
SATURN/DAC	RED		NONE		
TITAN (MARTIN)	GREEN		RED		
J.P.L.	RED		GREEN		
BOEING (MINUTEMAN)	BLUE/WHITE LETTERING	INERT	YELLOW		COLORS IN FED. SPEC. 595
BENDIX (LC39 MAGAZINE AREA)	WHITE W/BLUE LETTERING	INERT	NONE		
MCDONNELL	RED & WHITE CANDY STRIPE		RED		
POLARIS LMSC	YELLOW W/ BLACK STRIPE		RED		
HERCULES POWDER	NONE HOLES IN CASE		RED		
A.P.G. MARYLAND	BLUE		YELLOW		MIL-STD-709
DELTA D.A.C.	RED		NONE		
AEROJET	NONE W/YELLOW LETTERING	INERT	RED		
U.T.C.	BLUE		YELLOW		MIL-STD-709
THIOKOL	BLUE/WHITE LETTERING	INERT	YELLOW		
ARMY MISSILE COMMAND	BLUE		NONE		AR-385-65 MIL-STD-709
NAVAL ORDNANCE TEST UNIT	YELLOW W/ BLACK STRIPE		RED		SAME AS POLARIS
SCOUT (W.T.R.)	LETTERED INERT	INERT	NONE		

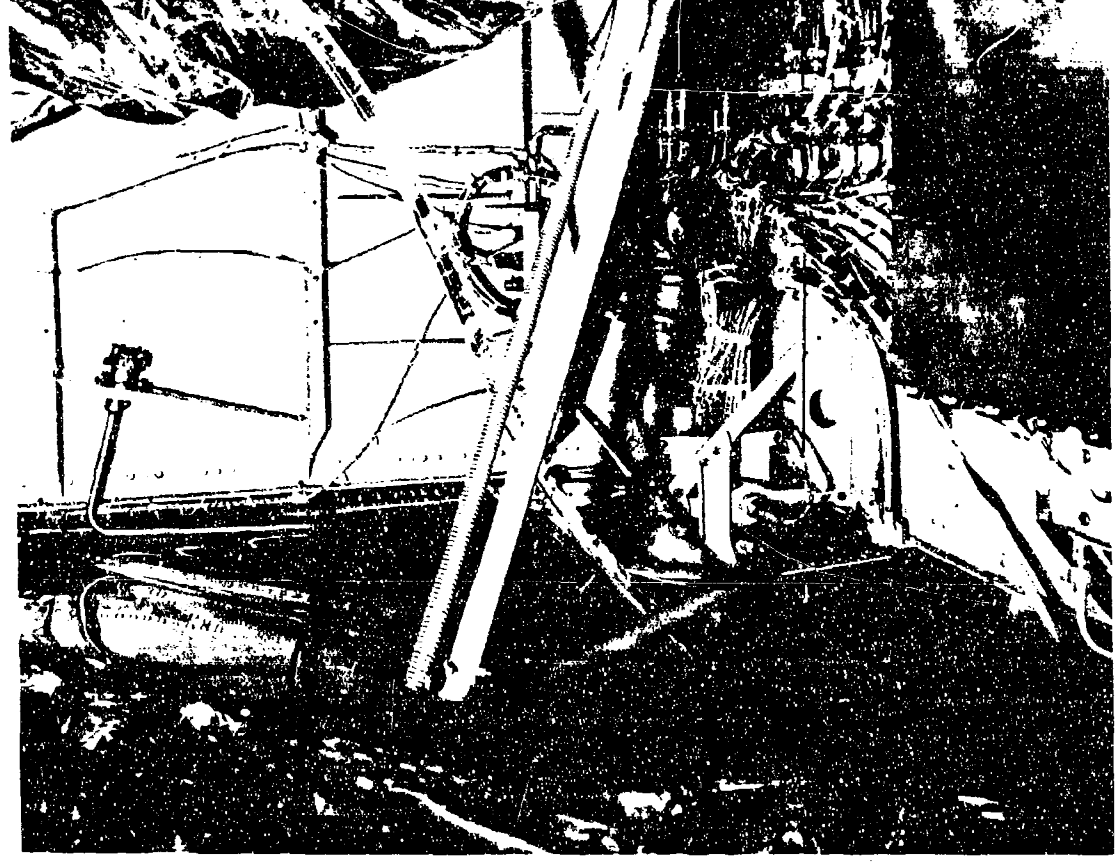

INCHES

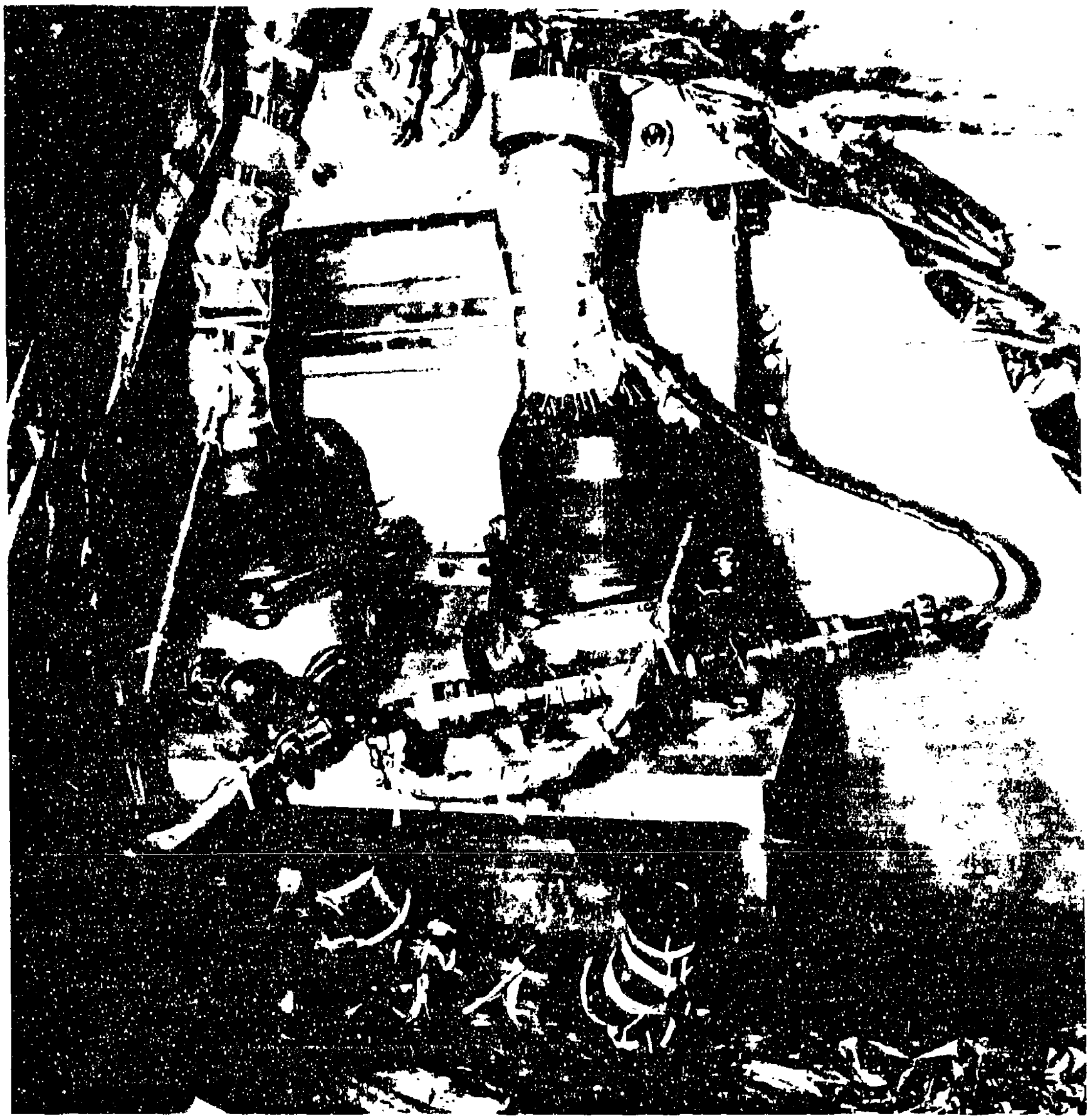

GQ9415
AMBIENT H₂ FILL











TEST FACILITY SAFETY:

ACCIDENT PREVENTION AND HAZARD CONTROL

MANAGEMENT SYSTEM - AIR FORCE ROCKET PROPULSION LABORATORY.

BY

BLUFORD B. GRAVES

ABSTRACT

PROVIDES INSIGHT INTO THE CONCEPTUAL AND PRACTICAL APPLICATION OF THE AIR FORCE ROCKET PROPULSION LABORATORY ACCIDENT PREVENTION AND HAZARD CONTROL MANAGEMENT SYSTEM. EXAMINES INHERENT, PROGRAMMED AND CREATIVE SAFETY RESPONSES AS A USEFUL WAY TO CONSIDER THE PREVENTION AND CONTROL OF ACCIDENTS. RELATES THE TECHNICAL AND MANAGERIAL PARAMETERS THAT PROVIDES THE OPPORTUNITY FOR SUCCESS IN THE PRACTICAL APPLICATION OF THE ACCIDENT PREVENTION AND HAZARD CONTROL MANAGEMENT SYSTEM. EXPLAINS THE ORGANIZATION MATRIX USED TO INTEGRATE THE ACCIDENT PREVENTION AND HAZARD CONTROLS AS DEVELOPED WITHIN SIX MANAGEMENT SETS: FUNCTIONAL, PROGRAM, PROJECT, TEST COUNTDOWN, TECHNICAL SAFETY EVALUATION AND OPERATIONS HAZARD CONTROL. DISCUSSES SELECTED TECHNIQUES USED IN THE DEVELOPMENT OF TEST COUNTDOWNS WITH EXAMPLES OF SPECIFIC HAZARD CONTROL APPLICATIONS USED WITHIN THE LABORATORY'S TEST FACILITIES.

1. INTRODUCTION

This paper is prepared for special presentation at the Thirteenth Annual Explosives Safety Seminar conducted by the Armed Services Explosive Safety Board. Several months ago the discussion of test facility safety was addressed as an appropriate and useful subject for presentation at the explosive safety seminar. The unique position of the Air Force Rocket Propulsion Laboratory as an agent in advanced development in rocket propellants and propulsion systems made its accident prevention and hazard control management system relative to test facility, test system and personnel safety a likely candidate for vigorous discussion, and with some hope provide useful hazard control techniques for consideration by attendees at this seminar. The discussion presentation will provide insight into the conceptual and practical application of the Air Force Rocket Propulsion Laboratory accident prevention and hazard control management system. Examine the inherent, programmed and creative safety responses as a useful way to consider the prevention and control of accidents. Relate the technical and managerial environment that provides the opportunity for success in the practical application of the accident prevention and hazard control management system. Explain the organization matrix used to integrate the accident prevention and hazard controls as developed within six management sets: Functional, Program, Project, Test Countdown, Technical Safety Evaluation, and Operation Hazard Control. Also discuss selected techniques used in the development of test countdowns with examples of

specific hazard control applications used within the laboratory's test facilities.

2. HAZARD CONTROL ENVIRONMENT

The technical and managerial environment, coupled with diversified and rapid change in test activities, to a large extent, determines the opportunity for success in the practical application of the laboratory's accident prevention and hazard control management system. And, it is to these environmental parameters to which we will direct our initial attention.

2.1 Technical Environment

First, within the technical environment, at the laboratory, test applications using high energy propellants and propulsion systems are routine. It is recognized that experimental test and development activities using high energy and toxic propellants in newly designed test systems entail potential exposure to hazards that are greater and more diversified than hazards associated with standard operations. High energy and toxic laden propellants are poised to strike with fire, explosion and toxic releases, etc. There is a high risk potential for personnel injury and death, and for major loss to the test system and facilities. The loss could result in a major interruption and delay in the test program. Therefore, should effective accident prevention and hazard control fail, catastrophic events are poised with

destructive potentials that may well scuttle a program and at the very least result in extensive delays.

2.2 Management Environment

With a potential catastrophic accident lance poised at mission success, laboratory management has responded on the fundamental premise that research and development activities, within this high energy technical environment, can be managed successfully with a high degree of people and equipment safety. This premise is given direction by executive policy:

> Each Air Force Commander. . .staff members and any person who takes part in. . .operation. . .or support activities must take a personal interest and active support for maximum safety. . .to prevent incidents/accidents.[1]

> . . .test and development activities. . .pose special challenges. . .hazards must be clearly identified and eliminated or controlled. Our continuing goal is maximum mission accomplishment with minimum accidents.
> Safety problems. . .must be anticipated and resolved throughout acquisition. . .concept . . .development. . .test. . .installation . . .[2]

AFRPL management has recognized that the implementation of accident prevention and hazard control policies require a part of the cost and time allocated to experimental test and development are chargeable to accident prevention and hazard control application.

The resource commitment recognition coupled with the executive safety policy parameters, and the premise that test and development can be managed with a high degree of people and equipment safety provides the managerial environment in which the AFRPL accident prevention and hazard control management system performs.

3. MODES OF SAFETY RESPONSES AND HAZARD CONTROL INNOVATION PROCESS

Insight into the inherent, programmed and creative safety response modes, along with a conceptual model by which individual hazard control innovations are processed will be briefly examined. This examination will provide a common approach in which to consider the responses in the hazard control management system at the laboratory.

3.1 Inherent Safety Response Mode

The inherent safety response is perceived as a result of the psychological impact experienced by individuals required to handle and test high energy propellants. High energy propellants are KNOWN for immediate and vigorous retaliation on people and hardware where failure to implement effective hazard control techniques has occurred. Thus, inherently a part of the safety responses are perceived to be a needed

and accepted action in the daily test activities. And the hazard controls are exercised by self-control in response to a KNOWN potential danger.

3.2 Programmed Safety Response Mode

The programmed or semi-automatic safety responses have evolved with experience and knowledge accumulated at the laboratory through actual test and development activities using high energy propellants. The programmed safety responses are guided by the policies, procedures, rules, technical instructions and safety criteria in use at the laboratory. Special attention is directed to the criteria for selection of test facility and system siting, preliminary gross hazard analysis, test countdown procedures and test hazard analysis, test area access controls and hazard control responses to safety operations parameters. The safety evaluation and operation hazard control management sets (Fig. 5), to be discussed later, tends to provide integrity to the programmed safety responses.

3.3 Creative Safety Response Mode

The creative safety response is a prized and most elusive safety response sought. It is developed in response to new and unique combinations of inputs into a test and development activity that presents a potential hazard. Test hazard analysis is the most productive tool used to provide the creative safety response. The preliminary gross

hazard analysis, test system hazard analysis and the operating hazard analysis are the most productive source for initiating the awareness to the need for a creative safety response. Requirements for special studies and tests to determine the degree and characteristics of a potential hazard are often identified.

Typical test hazard evaluation guides in use at the laboratory to enhance the programmed and creative safety responses are:

Unplanned Failure Events Guide - (Fig. 2)
Potential Sources of Hazardous Energy Guide - (Fig. 3)
Test Hazard Evaluation Guide - (Fig. 4)

3.4 Hazard Control Innovation Process

Figure 1 presents a model by which the process of hazard control innovation can be examined. The arrow at the top of the model represents the hazard identification and control knowledge bank. In the lower arrow the perceived economic, individual and social values are represented. Each hazard control innovation is considered to be initiated by recognition of a potential hazard control need coupled with a feasibility recognition. The need and feasibility recognition are coupled to form a hazard control concept. Then through the use of known data, search and research a hazard control solution is developed. The developed solution is applied and the hazard control experience is diffused into the knowledge and value banks. The process of hazard control innovation is a process of awareness, recognition, solution, development, use and diffusion into the

PROCESS OF HAZARD CONTROL INNOVATION

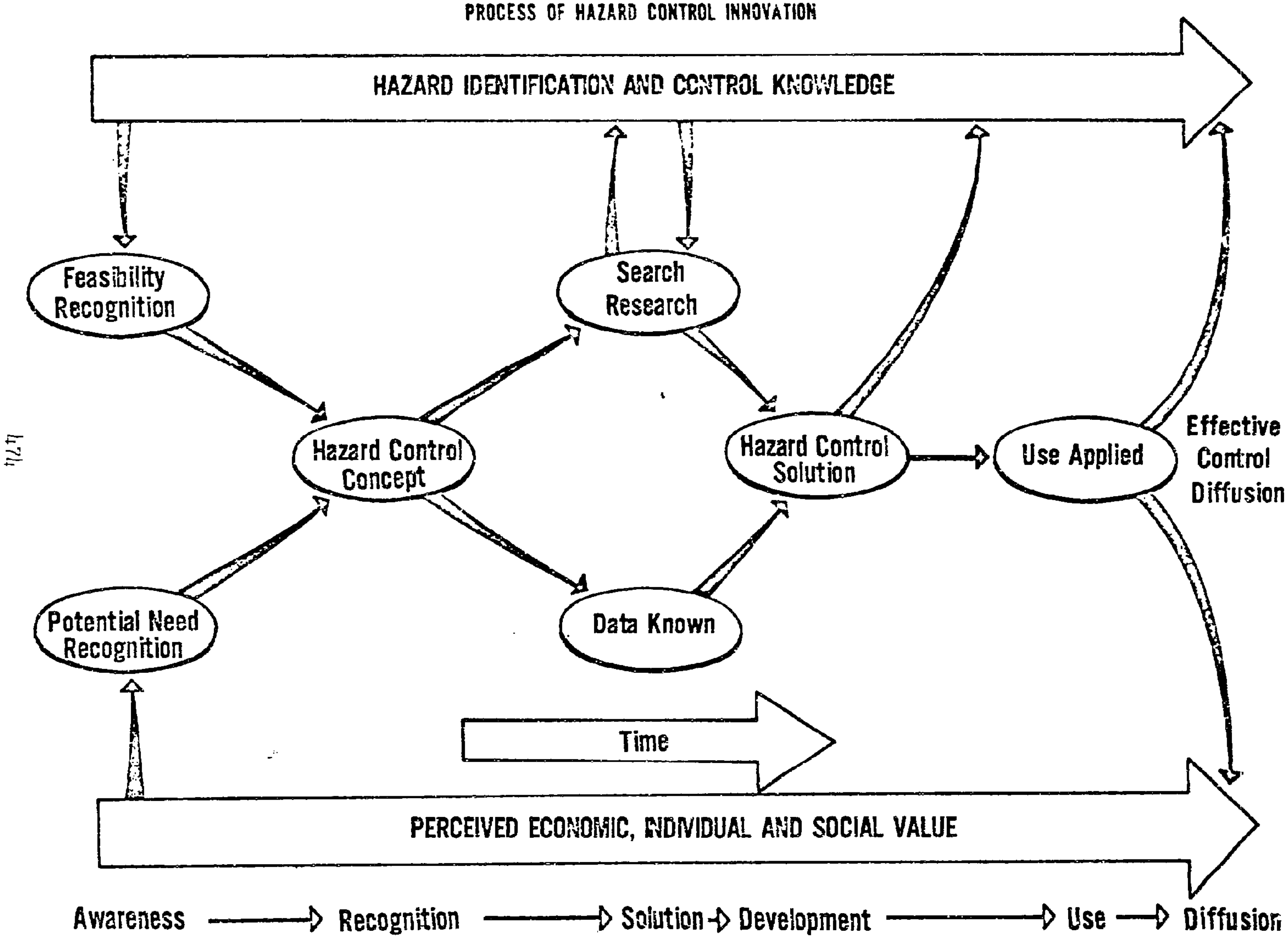


FIG. 1

UNPLANNED FAILURE EVENTS GUIDE

EVENTS		PEOPLE		EQUIPMENT
1	Fire	1 Injury	1	Interruption
2	Explosion	or		of
3	High Pressure Release	2 Death		Test
4	Toxic Release		2	Loss of Test System
5	Electrical Release			
6	Chemical Release		3	Loss of Test Facility
7	Sound Release			
8	Radiation Release		4	Mission Failure
9	Light Release			
10	Unknown			

FIG. 2

POTENTIAL SOURCES OF HAZARDOUS ENERGY GUIDE

1. Chemical Action:
   - 1.1 Decomposition
   - 1.2 Not Compatible
   - 1.3 Temperature (High Or Low)

2. Heat:
   - 2.1 Forced Air
   - 2.2 Steam
   - 2.3 Electrical
   - 2.4 Radiation
   - 2.5 Mechanical
   - 2.6 Chemical Action

3. Open Flame:
   - 3.1 Electrostatic
   - 3.2 Electrical Failure
   - 3.3 Mechanical Sparks
   - 3.4 Open Flame Devices
   - 3.5 Chemical Action
   - 3.6 Atmospheric Action

4. Mechanical:
   - 4.1 Impact
   - 4.2 Friction
   - 4.3 Stress (Shear, Pinch, Compression)
   - 4.4 Power Failure

FIG. 3

TEST HAZARD EVALUATION GUIDE

1. Procedure Hazards:

   1.1 In Error

   1.2 Omissions

   1.3 Out Of Sequence

   1.4 Warnings And Cautions Inadequate

   1.5 Sketches Designs, Test Prints In Error

   1.6 Omitted Back-Out Or Emergency Responses

2. Management Related Hazards:

   2.1 Use Of Non-Certified Personnel

   2.2 Insufficient Supervision

   2.3 Insufficient Inspection

   2.4 Inadequate Critical Incident Reporting

3. Test Equipment Hazards:

   3.1 Shutdown Procedures Inadequate (Normal And Emergency)

   3.2 Indicating/Warning Devices Ineffective

   3.3 Automatic Corrective Devices Malfunction

   3.4 Inadequate Interlocks For Sequential Events

   3.5 Devices And Instruments Not Calibrated

   3.6 Special Tools/Equipment Not Provided

4. Environmental Hazards:

   4.1 Toxic/Corrosive Gases

   4.2 Particulate Matter

   4.3 Temperature Extremes

   4.4 Humidity Extremes

   4.5 Excessive Noise

   4.6 Excessive Vibration

   4.7 Excessive Shock Levels

FIG. 4

knowledge and value system.

4. HAZARD CONTROL TASK DEVELOPMENT LEVELS

To provide an optimum opportunity for insuring the appropriate safety responses are selected and used within the technological and managerial parameters, AFRPL has an integrated accident prevention and hazard control management system. The accident prevention and hazard controls are integrated at four distinct test and development task levels. The task levels being program, project, test countdown and operation hazard control development levels.

4.1 Program Task Development Level

At the program task development level, conceptual test and development requirements are identified relative to mission support. Test facility design and siting parameters are considered. The gross hazards are identified. Hazards that could result in catastrophic events are of primary consideration, such as:

- Fire
- Explosion
- Toxic
- Radioactive
- Electromagnetic
- Noise and other environmental pollutants

The preliminary gross hazard analysis is made to identify the primary energy sources and the relative risk poised to potential

personnel exposures, adjacent test facilities and systems.

4.2 Project Directive Task Development Level

At the project directive task development level the premise and specific objectives for the test and development project are defined. Resources, plans and schedules are identified for approval to accomplish the test and development objectives. The gross hazards identified at the program development level become more definitive relative to a specific test facility and time. Analysis at this task level may reveal new potential hazards that were not previously considered and at the same time determine if previous hazard control actions are still adequate. For example, additional support studies and tests may be required in order to safely proceed with the tests and development operations.

4.3 Test Countdown Task Development Level

During the test countdown task development level the engineering design, fabrication and procedures for the test system are completed. Specific design criteria 's applied in the fabrication process. Overall and sequential test operating procedures are developed. A test system hazard analysis is made, specific hazards are identified and the appropriate hazard controls are integrated into the test system. Meteorological and bio-environmental limits are refined to include specific toxic exposure limits and toxic

corridor constraints to be used when test firing, and a technical safety evaluation is performed on the proposed test system and countdown procedures.

4.4 Operation Hazard Control Development Level

The operation hazard controls includes the scheduling and real time control for test firings. Real time meteorological data such as temperature, wind direction and velocity, humidity and prevailing weather predictions are monitored to insure potential danger and toxic corridors are within the approved test firing constraints, and safety surviellance of the first test firing.

5. ORGANIZATION HAZARD CONTROL MANAGEMENT MATRIX

Figure 5 represents the AFRPL organization hazard control management matrix used to integrate the accident prevention and hazard control test requirements. Each management set consist of selected scientists, engineers,and technicians (SET). Six management SETs are used at the laboratory to integrate accident prevention and hazard controls into the experimental test and development activities.

Functional Management SET (FMSET)
Program Management SET (PMSET)
Project Directive Management SET (PDMSET)
Test Countdown Management SET (TCMSET)
Technical Safety Evaluation Management SET (TSEMSET)
Operation Hazard Control Management SET (OHCMSET)

AFRPL ACCIDENT PREVENTION & HAZARD CONTROL MANAGEMENT SYSTEM MATRIX

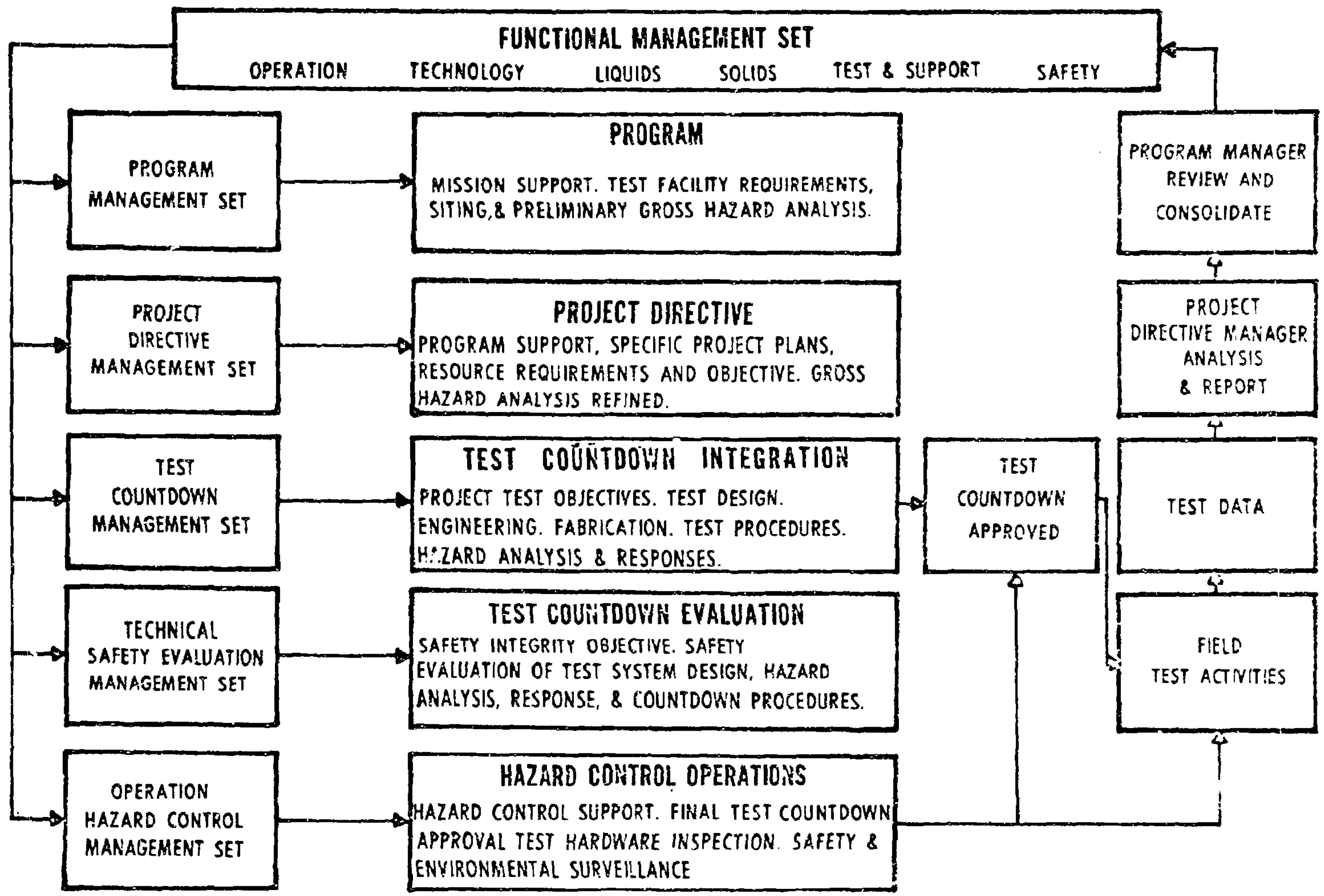


FIG. 5

5.1 Functional Management Set

The functional management set at the laboratory consists of the general line and staff management functions that provide the basic organization structure used to accomplish the experimental research test and development objectives. The functional set includes Technology, Liquid, Solid, Test and Support, Operations and Safety. The other management sets represented in the hazard control management system matrix are sub-management sets comprised of scientists, engineers and technicians selected from the primary functional management set.

5.2 Program Management Set

The program management set is usually managed by a senior scientist selected from the Liquid, Solid or Technology division. Emphasis is given to specific program knowledge as it relates to overall mission requirements and related experimental test and development projects. The basic process for hazard control innovation is initiated with this set. Awareness of the potential gross hazards are paramount and through search and research adequate control knowledge is identified.

5.3 Project Directive Management Set

The project directive management set usually consist of a sub-set selected from the program management set and focuses resources on a single project. Emphasis is given to authority of knowledge as

it relates to the contribution a specialist can make to the project. The project manager is usually a scientist or engineer and by research and direct participation with other knowledgeable scientists, engineers and technicians develops the basic project directive test and development plans. The potential gross hazards are related to a specific project and through search and research identify supporting hazard control test needs, and adequate time and resources are allotted to the project. In turn, the project directive is reviewed and evaluated by the functional management set and approved by the commander.

5.4 Test Countdown Management Set

The test countdown management set consists normally of a sub-set of scientists, engineers and technicians from the test and support division. The focus is on the engineering design, procedures and the technical expertise required to meet the test and development objectives as given in the project directives. The test countdown manager is an integrator of project requirements and technical feasibility. In the process the test countdown manager provides test system design and fabrication, test hazard analysis and test countdown procedures with the guidance and support of a senior test area engineer, with mechanical and instrumentation support resources. The test countdown management set has final test commitment responsibility and as such must insure adequate hazard control actions have been completed prior to initiating a test firing.

5.5 Technical Safety Evaluation Management Set

The technical safety evaluation management set provides safety integrity into the test design and countdown procedures. The safety evaluation management set consisting of scientists, engineers, and technicians are selected from the functional management set, and appointed by letter for the express purpose to review and evaluate the test system, procedures and test hazard analysis and hazard control responses to insure optimum accident prevention technology and hazard control parameters are adequate and have been integrated into the test and development activity. This set is often referred to as the safety integrity set because of its third party interest as an agent of the laboratory safety officer.

5.6 Operation Hazard Control Management Set

The operation hazard control management set provides final test system inspection, operation and safety support. The set performs the final field inspection of the test facility and test hardware configuration to insure safety criteria has been integrated into the test system. The set provides operational support, such as, real time meteorological and current potential toxic hazard corridor parameters to insure test firings are activated within the established safe test constraints. In addition, the set provides disaster preparedness support, that includes fire fighting, medical and security response. Finally the set provides field safety surveillance to evaluate the use

and effectiveness of the test countdown during the first test hot firing.

6 TYPICAL TEST FACILITY HAZARD CONTROL APPLICATIONS

Typical test facility hazard control applications in use at the Air Force Rocket Propulsion Laboratory that have been selected for discussion are:

Personnel Access Control and Alert Features

Hazard Control Area and Potential Toxic Corridor

Remote Handling of Sensitive Propellants

Solid Propellant Dust and Chip Collector

Shield and Remote Control Techniques for Compressed Gas Cylinders

Test Cell Fire Suppression

Test Chamber Door and Dome Over Pressure Relief Techniques

High Altitude Test Chamber Exhaust Scrubbers

Laser Beam Sensing Element

6.1 Personnel Access Control and Alert Features

Test facility personnel access control and alert techniques are directed at minimizing the exposure of personnel to potential hazards associated with the test operations in the designated test areas. Several positive methods of personnel access control are exercised to minimize the risk. One, the operation status of all facilities is maintained on a visual display board at the laboratory test operations central test control center. A visual display board

provides current test facility operating status by which real time decisions are made to control personnel access. Two, the senior test engineer at each test facility maintains a visitors access log to insure personnel in the area are cognizant of current hazards and to maintain awareness of the number of transient personnel in the area should an unplanned failure event occur. Three, visual test facility status and control lights are strategically located in each test area. Light indications are as follows:

GREEN. . . .Test Facility Clear.

AMBER. . . .DO NOT ENTER unless essential and specifically authorized by the test facility engineer.

RED. . . .Danger. DO NOT ENTER

CONTINUING KLAXON SIGNAL WITH RED LIGHT. . . .Evacuate test facility or enter approved shelter.

Four, warning signs and trafficway blocks are used to control access to the test facilities. Five, public address systems are used to announce the activation of a hazard control area, and again to announce its termination. Six, klaxon horns in combination with a red light are activated to indicate an emergency and that immediate actio. be taken to evacuate the test area or enter an approved shelter.

6.2 Hazard Control Area and Potential Toxic Corridors

Hazard control area and potential toxic corridor limits are defined for each test. A hazard control area is usually circular, with the minimum radius being the distance prescribed for inhabited buildings

in the Department of Defense Manual for Ammunition, Explosives and Related Dangerous Materials. Potential toxic corridor limits are evaluated for each test project and where toxic propellants are being used toxic corridor parameters are determined by integrating the rocket exhaust products, bio-environmental tolerance levels and meteorological constraints.

Bio-environmental limits are established at the laboratory on the premise that (1) Where people could be subject to a potential exposure, they are part of a controlled population and subject to immediate evacuation controls. (2) The limits take into consideration the physical limitations relative to age and minor respiratory degradation as experienced in the general population.

Meteorological conditions are monitored in real time at 19 instrumented towers dispersed at strategic locations within the laboratory test area. In total there are 73 sensors measuring wind direction and speed, temperature, differential temperature, dew point, pressure and net solar radiation. Each sensor automatically calibrates every thirty minutes, prints out the data on graph paper and provides teletype outputs coupled with a real time map display indicating wind speed and direction. In addition, the "Micro-Met" system can be activated to provide real time meteorological conditions.

6.3 Remote Handling of Sensitive Propellants

The solid propellant test facility laboratory is equipped

with remote control mechanical devices to perform sensitive propellant handling and test operations. Remote mechanical fingers are used to operate the test propellant mixers which are installed in test cells. Emergency propellant mix dump tanks containing a neutralizing solution are positioned under each mixer. And by remote valve control a hazardous propellant mix can be dumped and desensitized to reduce the risk of a potential explosion.

Also, a mechanical robot equipped with a televised monitoring eye is used to handle test propellants. The robot is controlled from a control station with a television monitor screen. The robot has a maximum mechanical arm lifting capacity of 50 pounds and a remote control hoist lifting limit of 300 pounds. In addition, the robot monorail cable carrier has a 200 foot travel limit, and the robot, has a maximum radius of 50 foot in which it can be manuevered.

6.4 Solid Propellant Dust and Chip Collector

The solid propellant cutting and shaping test facility is equipped with a hydro-vacuum system designed to trap the propellant dust and chips. The propellant dust is exhausted at the cutting point and routed into a water trap. The hydro-vacuum system removes sensitive propellant dust particles from the cutting and shaping machinery and by water emersion of the dust it tends to desensitize the propellant and reduce the risk for explosion.

6.5 Shield and Remote Control Techniques for Compressed Gas Cylinder

Compressed gas cylinder containing hazardous propellants requires special handling to minimize personnel exposure. Shielding and remote valve control are two techniques in use at the laboratory. One example is a portable fluorine passivation trailer, on which a fluorine gas cylinder is installed in a metal coffin and the valves are remotely operated behind a protective shield. In addition, a helium compressed gas cylinder is installed on the trailer to provide a source for pressure valve equalization, diluent and purge during the passivation process.

6.6 Test Cell Fire Suppression

Each test cell is equipped with a water deluge fire suppression system. The fire suppression system has automatic and manual control capabilities, with water fog deluge outlets located at the top and floor of the test cell.

6.7 Test Chamber Door and Dome Overpressure Relief Techniques

Two methods, that may be of interest, are the door and dome emergency pressure relief techniques used in the altitude test chambers. The access door to the high altitude test chambers are designed to open when an overpressure condition is experienced in the test chamber. After the desired altitude test conditions are obtained in the chamber, the

chamber door lock is released and should an explosion or overpressure condition occur in the chamber the access door opens and allows the excess prèssure to escape. Also, the dome on the vertical altitude test chamber is designed to allow for emergency pressure relief should an overpressure occur in the chamber. The dome is equipped with placement clamps and vertical travel rods that allow the dome to rise when an overpressure condition is experienced inside the chamber. This in turn minimizes the potential for a catastrophic chamber rupture.

6.8 High Altitude Test Chamber Exhaust Scrubbers

The altitude test chambers are equipped with water and char-coal gas scrubbers to control toxic exhaust products during test rocket engine firings. The exhaust gases are routed through a vertical tank in which a water spray is introduced to trap exhaust particles in a water solution. The contaminated water mixture is then routed to a catch tank, and in turn the contaminated water is pumped through a tank containing a neutralizing agent. Then, the neutralized solution is analyzed by the bio-engineer and when the solution has been neutralized it is released to a dump tank and allowed to flow back to the water shed.

Some tests, use small charcoal scrubbers to neutralize residue toxic propellants that remain in the test system run-line after a test firing. The residue propellant is usually gas purged from the lines and routed into the charcoal where it is neutralized.

6.9 Laser Beam Sensing Element

In the development of high energy laser systems at the laboratory a special laser beam sensing element is in use to effect an automatic propellant flow cut-off. In essence the laser beam sensor consists of a metal cube shape frame, laced with belted sensing wire. Should the laser beam strike the sensing belt the energy source to the laser is programmed for automatic shut-off.

7. CONCLUSION

This short excursion into test facility safety as practiced at the Air Force Rocket Propulsion Laboratory provides some insight into the managerial complexities and empirical techniques currently being practiced. Some practical advantages have been reaped from the use of the multiple management sets to integrate accident prevention and hazard control techniques into the test and development activities. One, the management set approach provides a high degree of safety into multiple and diverse test and development activities with a minimum safety staff. Two, the management set approach provides maximum flexibility in assigning knowledgeable scientists, engineers and technicians to insure a high degree of safety integrity is included in each test activity. Three, the changing management sets tends to promote diffusion of the current hazard control practices and at the same time maintain an excellent degree of safety awareness within

the laboratory management system. In summary the management set approach makes safety a positive force at the laboratory. In part this positive force stems from the education and associative motivation reaped from the interactions of the separate management sets. In essence the individuals participating in separate and changing roles associated with the multiple management sets develops an acute awareness for the need to implement positive hazard control applications.

MG Erwin M. Graham, Jr
Commanding General, US Army Munitions Command

NEW HORIZONS IN THE FIELD OF EXPLOSIVES

I am indebted to speakers who preceded me, particularly, Secretary Sheridan, because they set the stage for what I have to say on NEW HORIZONS IN THE FIELD OF EXPLOSIVES. By the term "explosives" I am including not only high explosives such as TNT but also propellants, pyrotechnic materials, and similar energetics which are basic components of munitions ---- and in the context of the total spectrum of the life cycle rather than any one particular phase of that cycle.

As a change of pace, I have divided my time on the program into two parts. First, a discussion of what we are doing in the way of new and improved product programs ---- advancements in process technology which have a heavy safety impact --- and efforts to upgrade and strengthen ammunition service in the field. Second, a film report on what we are doing in the modernization of our ammunition plants.

All of the things I plan to talk about or show in the film today have a bearing on improving safety in the explosive field. It is also worth noting that most of those things offer not only improved safety but pollution abatement, increased cost effectiveness, and increased responsiveness to customer requirements as well. SAFETY IS GOOD BUSINESS!

OBJECTIVES OF ARMY EXPLOSIVES R&D

We are pursuing seven broad objectives for improvements in existing, and new concepts of, explosive products and processes. These are:

1. Increased performance or usable energy for specific munitions applications.

2. More cost-effective formulations.

3. Better characterized stability under more exacting physical and chemical conditions.

4. Better controlled and defined sensitivity to initiation by external stimulation.

5. New initiation schemes and designs.

6. Improved methods of manufacturing, processing and loading explosives to meet cost, safety, regulatory or statutory requirements.

7. Improved measurement techniques and data on the characterization and properties of explosives and their reaction products.

Achieving these objectives requires the solution and integration of many complex and detailed problems which collectively contribute to the larger understanding of explosives. Thus our R&D Program includes effort directed towards developing, characterizing and evaluating explosive formulations; determining the feasibility and practicability of producing formulations up to the pre-pilot scale; and using such formulations in various classes of munitions.

TYPICAL AREAS OF ARMY R&D INVESTIGATION

I have selected several typical areas currently under investigation to illustrate the nature of the Army's Explosives R&D Program:

The first area is new synthetic routes for conventional explosives. There are two aspects of the problem we are pursuing:

1. The use of new chemical reaction schemes promising increased efficiency, and

2. the improvement of existing processes to eliminate pollutants, impurities or other undesirable by-products.

Programs are now underway to develop more economical, less polluting processes for the manufacture of TNT as well as new synthetic routes for more expensive explosives such as RDX and HMX. Because of the Army's responsibility to supply these explosives in support of all of DOD, these programs have received particular emphasis in recent years.

The second area is synthesis of new molecular structures aimed at the discovery of explosive molecules with increased destructive potential. Other important attributes include improved resistance to degradation at high temperatures and improved resistance to atmospheric chemical conditions, to electromagnetic and nuclear radiation, to fission fragment damage and decreased sensitivity to accidental initiation.

The third area is crystal growth and characterization of explosives. The characteristic chemical and physical properties of explosives, propellants and other energetic materials depend significantly on the conditions under which they are prepared. In particular, the understanding of the process of the explosive decomposition reaction requires knowledge of

the single crystal state of the substance. Further, the development of compositions that must meet critical specifications imposes additional demands on the ability to characterize them with precision and accuracy.

The fourth area is pollution abatement technology. The need for effort in this area was eloquently described in Secretary Sheridan's Keynote Address. This area is receiving considerable engineering emphasis in today's environment. However, some of our problems in pollution abatement require longer range research beyond strictly engineering solutions, and we have accordingly prepared and are started on an extensive R&D effort that includes new processes and materials; treatment of effluents and wastes; detection and measurement; toxicity characteristics and physiological activity of materials and wastes; metal parts fabrication and lubricant pollution.

Often, a new process offers the best chance to eliminate a pollution problem. For example, eliminating sulfuric acid from the process for the nitration of cellulose, eliminates sulfur dioxide air pollution and the output of insoluble sulfates into the water effluent.

Many of explosive process effluents contain materials for which there is no process for abatement. These are usually materials such as soluble nitrates, insoluble sulfates and the like, which while not noxious or toxic in the usual meaning of the term, must be controlled to meet the strict standards in effect or expected to be enforced in the future. We are attacking the problem now so that we will be able to meet these standards when they are strictly applied.

One of our biggest problems is simple knowledge of what the effluents contain and developing techniques for the reliable measurement and

monitoring of the relatively small percentages of impurities or unwanted substances in these effluent streams.

Our R&D Program is attacking difficult problems but their solution means better, cheaper, and safer explosive materials and processes.

DISPOSAL AND DECONTAMINATION

As Secretary Sheridan pointed out in his address "the anti pollution laws mean SAFE air for people to breath --- SAFE water for them to drink --- and protection from radical changes to the ecology of an area when we do not know what effect these changes will have on the totality of man's environment." This is particularly applicable to the field of disposal and decontamination. Within the past several years Edgewood Arsenal developed, engineered, and installed disposal systems at two of our facilities against impeccable standards and criteria which are far more stringent than any that have existed in the past. We developed these standards and criteria. They were reviewed all the way to the Presidential Scientific Advisory level. We had to demonstrate the environmental impact of the application of these standards and criteria to gain approval. The new disposal systems are now in operation.

We are also engaged in a systematic program to identify, review, and formulate programs for the decontamination of areas which in earlier years were subjected to disposal techniques which are no longer acceptable in today's environment. An automated management information system has been designed to aid us in managing our decontamination program so that we can effectively execute the necessary actions consistent with National Policy. The system just completed its test phase and will be implemented shortly.

MODERNIZATION OF AMMUNITION PLANTS

We went into the SEA period with munitions plants that were designed and still reflect mostly 1930 and 1940 technology -- or even earlier -- and updated in some instances by a substantial process engineering program

in the late 50's, that was stimulated by the Korean Emergency. From this came such improvements as the Red Water Disposal System; solventless propellant mechanized roll process; slurry and pneumatic transfer of explosives; controlled cooling of projectiles; and many other techniques. However, we were unable to really complete the job. Certain areas were left completely to industry, such as Nitric Acid technology. In other cases, the Government was unable to participate with industry due to lack of funds in such areas as Nitrocellulose and TNT.

The reactivation of the ammunition production base to support SEA included a need to expand our explosive manufacturing capacity. This led to the $64 question, "What is the best process to employ in the expansion program?" There were searching questions raised not only with respect to new processes but old processes as well. Pollution abatement, safety, cost, and economic factors played a major role in getting answers to these questions. There was also the question of what do we layaway after SEA and what shape will the base be in. Out of all of this has emerged what is now known as the Army's Ammunition Plant Modernization Program. I am going to hit modernization hard because it offers the opportunity to simultaneously attack <u>and solve</u> a host of problems as demonstrated by the film you will see following my remarks.

Our modernization programs are based on process engineering concepts which have the following objectives which are of particular interest to you here today:

1. A reduction in the number of operating personnel, thus leading to a reduced exposure of personnel to production hazards.

2. Emphasizing remote control operations, thus removing personnel from the source of the hazard.

3. Development of less hazardous processes using, in particular, techniques of safety hazard analysis.

The propellant area is a case in point. The manufacture of single-base cannon propellant involves a product that is basically nitrocellulose with certain additives. It is a high volume product that historically has been produced by batch operation. We have recently developed a process that will permit its manufacture in a continuous automated manner.

VUGRAPH 1 - BATCH METHOD VS CONTINUOUS PROCESS HANDLING

In the batch method, material is manually handled. In the continuous process, remotely controlled and monitored, modern automatic processing and handling equipment will eliminate manual handling and minimize personnel exposure.

VUGRAPH 2 - BATCH VS CONTINUOUS PROCESS FACILITY REQUIREMENT

The batch method requires the operation and maintenance of 42 buildings to produce 2.5 million pounds per month. The same amount can be produced by the continuous process in 4 oper[illegible] [illegible]uildings.

VUGRAPH 3 - COST, PERSONNEL, AND EQUIPMENT COMPARISON

The modern continuous process means savings in cost, personnel, and equipment.

VUGRAPH 4 - SAFETY COMPARISON

The modern, continuous process eliminates the kinds of operations which are especially accident prone.

VUGRAPH 4 OFF

We now have a major program underway to establish a continuous process to manufacture Composition B. Presently, we have only one plant available

to produce RDX. Aside from problems of capacity and obsolescence, recent data raises serious questions on the hazard classification of certain operations in the present design. We are now designing equipment to revamp one of our existing production lines to produce 7.5 million pounds of composition B in a continuous fashion. From this prototype, we will design entirely new facilties for Holston which will meet all safety criteria and exploit the current state-of-the-art in equipment, material handling and principles of constructing explosive protective structures.

SAFETY ENGINEERING IN AMMUNITION PLANTS

My next example is an engineering program entitled "Safety Engineering in Ammunition Plants" which we have established.

This program, supported by the process engineering budget, is concerned with process design problems common throughout the explosives industry. Some of them are well known to you from previous papers given in former years at these meetings.

The point I want to make is that for the first time we have succeeded in establishing a recognized and funded program to provide needed data in the following areas:

1. DESIGN OF PROTECTIVE STRUCTURES
2. TNT EQUIVALENCY STUDIES
3. CRITICAL DEPTH STUDIES
4. MINIMUM SEPARATION STUDIES
5. FACILITY SAFETY DESIGN ANALYSES

NEW MELT POUR PROCESSES

In the film that follows my remarks you are going to see specific illustrations of new horizons in explosive safety. New melt pour processes are a case in point.

In 1968, over 12,000 pounds of cyclotol exploded in the melt pour facility at one of our plants resulting in a complete loss of the load line. As in the case of the Hercules explosion in the early forties, the post mortem led to the initiation of substantial improvements.

VUGRAPH 5 - CONVENTIONAL MELT POUR FACILITY

The conventional melt pour facility is a three story building with extremely high explosives exposure shown on this vugraph. The entire operation is characterized by high personnel exposure, high explosives quantities, high manufacturing costs and high capital costs.

It was clear that a major effort was needed to reduce the personnel and explosives exposure. Our operating environment required also that it would reduce manufacturing costs. Our studies indicated that to achieve these goals we would have to reduce the height of the melt pour structure from three stories to one story above ground; to separate the melt units by new design dividing walls to prevent propagation between melt units; and to automate the facility to reduce personnel exposure.

VUGRAPH 6 COMPARISON OF BATCH VS CONTINUOUS MELT POUR PROCESSES

This shows a comparison of the explosives allowance and personnel exposure at a common production rate for existing batch and modernized plants.

VUGRAPH 7 - AUTOMATED MELT POUR PROCESS

This vugraph portrays our concept of the automated melt pour process. The essential or most important part of this system is a recycle system which keeps the molten explosives circulating through the system.Explosives draw off can be accomplished at the loading point for any requirement other than the melt system.

You will notice that pumps and detonation traps are an essential part of the system. In order to reduce personnel exposure and the quantities of explosives, it was necessary to move the explosives at a more rapid rate than the present batch system which depends entirely on gravity flow. Our design agency developed a pump specifically to satisfy this requirement. The melter system with these pumps has been successfully tested on a laboratory scale. Currently, a pilot plant is being established to test its system on a larger scale.

A primary safety consideration was that a detonation in one melter could not be allowed to propagate out of the melter area. This was a significant problem since the pumping of the explosives from the melter to the loading area is a continuous flow of explosives between the facilities. To prevent propagation in these molten explosives lines, Picatinny Arsenal has developed a detonation trap concept.

VUGRAPH 8 - DETONATION TRAP APPROACH

This is the detonation trap concept that is the heart of the Safety of the automated process.

The concept is, if you have a detonation in a molten explosive line you can beat the detonation somewhere downstream, by closing off the line and stopping the propogation. When a detonation occurs in the line, the pipe ruptures and fractures a breakwire, thus activating an electrical impulse

which is transmitted to the initiator, in a cartridge actuated valve, which fires and forcefully injects a steel plug radially into the line.

VUGRAPH 9 - PROTOTYPE DETONATION TRAP MOD 111

The left view of this vugraph shows the open position--- The right view shows the closed position of the trap.

As the detonation wave propagates through the explosive, it encounters the steel plug which blocks its passage and attenuates it. This detonation trap has been tested and proven feasible. Further testing is being conducted to establish the parameters for such traps for various explosives lines.

RISER SCRAP

There is another aspect of explosive safety we have addressed in our continuous melt pour system -- RISER SCRAP RECOVERY. Old methods for recovery of riser scrap present a significant hazard. We have therefore developed a new approach shown on this vugraph.

VUGRAPH 10 - RISER SCRAP RECOVERY

This is a process that eliminates all of the manual handling associated with old methods. Not shown are those automated processes that remove, extract, and delivery user scrap to this rework separator that re-introduces the molten material to the melter.

VUGRAPH 11 - CONTINUOUS RISER MELTER

This melter system is designed as a recycle system so that the explosives can be fed into the melter units and flaked on a belt; the water effluent overflows and goes through a filter to take out some of the entrained explosives and is then recycled back into the unit to melt additional material.

SHELL COOLING

Another area is getting attention. Shell cooling is one of the greatest explosives exposure hazards in the existing load lines. The shells are put into cooling bays and stay there for six, eight, and twelve hours. This system necessitates a large amount of explosives exposure.

VUGRAPH 21 - ZONE COOLING METHOD

Picatinny Arsenal is developing a zone cooling method by putting hot water in the top zone to keep the top molten and putting cold water in the bottom zone to cool it. By this method we will cool from the bottom up which should result in a near perfect cast, eliminate the need for probing and materially reduce the amount of explosives items held in an area at any given time.

VUGRAPH 12 OFF

PROPELLANT CHARGE LOADING & ASSEMBLY

Bag loading methods are getting a good deal of attention because they also represent a high exposure situation.

VUGRAPH 13 - MANUAL 105MM PROPELLANT CHARGE LOAD & ASSEMBLY SYSTEM

Existing methods which date back to World War II are highly dependant upon manpower availability. They consist of a conglomerate of hand fed machines requiring many operators with a high personnel exposure and manufacturing cost.

VUGRAPH 14 - WEIGHING OPERATION

The weighing operation requires many individuals spaced no more than one to two feet apart.

VUGRAPH 15 - MANUAL BAG LOADING

The typical manual bag loading operation shows more evidence of high personnel exposure.

VUGRAPH 15 OFF

The Army Munitions Command has conducted numerous evaluations of current load, assembly and pack operations with the result that new systems concepts and a number of "element concepts" appropriate to those new systems have been developed.

VUGRAPH 16 - AUTOMATED 105MM PROPELLANT CHARGE LOADING & ASSEMBLY SYSTEM

In the case of the 105mm propellant charge, a full scale systems concept has been developed which will result in:

1. Reduction of 164 operating personnel in the manual process to 26 in the automated. This 85% reduction in exposure will greatly reduce hazards.

2. Improvement in quality by producing an end product of greater precision which would make it more reliable for use.

3. A significant reduction in operating cost.

4. Attainment of a higher production rate.

I want to emphasize that our "systems concept" provides for hazards analysis of each process step.

VUGRAPH 16 OFF

HAZARD ANALYSIS

In the process of eliminating safety problems, we are creating a new safety environment, which requires that our safety attitudes and techniques must be updated and reoriented. Accordingly, during this past year a significant step forward was taken with the issuance of an Army Munitions Command regulation on hazards analysis which takes into account the following considerations:

1. Avoiding, eliminating or reducing identified hazards.

2. Controlling and minimizing hazards which cannot be eliminated.

3. Isolating hazardous substances.

4. Using fail-safe devices to prevent catastrophes.

5. Human engineering in equipment location.

6. Avoiding physiological and **psychological stresses.**

7. Providing suitable warnings and instructions for personnel protection.

8. Minimizing severe damage or injury to personnel.

We have instituted a requirement for hazards analysis studies throughout the various life cycle phases of the modernization program including concept formulation, process development and facility design. These studies provide for the timely identification of hazards and the initiation of those actions necessary to prevent or control these hazards within the process system. This philosophy is now basic in all of our programs.

Hazards analysis emphasizes the quantitative assessment of process-production conditions in engineering terms and establishment of material response to stimuli found in the process. Thus, with bbth process-production potential and material response expressed on a common basis, the problems or hazards are to be quantitatively measured.

Non-obvious hazards can best be identified through use of analytical tools such as fault tree analysis. Also, various statistical methods are being considered to use information acquired in the past in reinforcing data currently accummulated.

HAZARD CLASSIFICATION

The Army Munitions Command has been conducting a hazard classification evaluation program for pyrotechnic compositions since 1969.

These studies are well advanced in the development of a series of tests which can determine the deflagration to detonation characteristics of pyrotechnic compositions more quantitatively and qualitatively. The tests developed include the following areas:

1. RATES OF PROPAGATION
2. BLAST PRESSURE MEASUREMENTS
3. CONFINED IGNITION TEMPERATURE
4. PRESSURE-TIME BEHAVIOR
5. THERMAL STABILITY
6. SENSITIVITY TO IMPACT, FRICTION AND ELECTROSTATICS

We plan in the near future to make some specific recommendations on introducing these tests into regulations. At this point, I will summarize some of the findings resulting from the evaluation program.

This evaluation program has already demonstrated that the tests prescribed by TB-700-2 do not properly determine the hazard classification for pyrotechnic compositions. There is overwhelming evidence that the GO-NO-GO impact sensititivty test should be disregarded for pyrotechnic compositions. The evaluation program discloses that the detonation and card gap tests are also of questionable value.

This program has been extended to develop methods of classifying pyrotechnic materials which will be consistent with their potential for damage and the hazards they present in processing, storage and deployment.

Studies are being conducted to develop pyrotechnic hazard criteria and damage indices and to identify the critical parameters to improve safety in pyrotechnic operations. The application of these means of classification to present operations and items should result in increased safety while reducing costs. This will be the results of more realistic classifications leading to less complicated and costly storage and transportation requirements. Improved classifying methods will also reduce the expense involved in classification of pyrotechnic materials because of simplification of the testing process. The knowledge of critical meterials parameters will aid in classification and reduce the uncertainty involved in pyrotechnic oper tions.

AMMUNITION SERVICE IN THE FIELD

Up to this point the main thrust of my remarks has been oriented towards the CONUS establishment. I would now like to turn briefly to ammunition service in the field.

Hand-in-hand with improvements in the CONUS establishment there must be improvements in the field. We must support both if we are to perform our basic mission properly. In the final analysis, the payoff in whatever we do in the CONUS establishment is determined by what happens in the Field Army. This was particularly brought home to me during my tour as an Ordnance battalion commander in Korea and more recently on my overseas visits as CG of the Army Munitions Command.

We must recognize, **and provide for,** the fact that the man in the field must operate in a totally different environment from that which exists in the CONUS establishment. With that in mind during the past year a Field Service Office was established in my Headquarters comprised of military

personnel, who have just returned from tours of duty with ammunition assignments in the Field Army supported by a small competent group of civilian technical experts. (We rotate military personnel through this office to assure a continuing fresh viewpoint of the man in the field.) The mission of this office is to inject into our programs and projects the needs of the ammunition man in the field and to see that those needs are satisfied in a practical way consistent with the field environment. This runs the entire gamut of improvements in packaging and packing, containerization, storage, handling, care and preservation, and renovation and other aspects that affect the field. Improvements mean improved safety because it is impossible to separate one from the other. This Field Service Office is working with activities outside the Munitions Command as well as those inside --- wherever there is an opportunity to stimulate and contribute to its basic mission. Our program is in its infancy but we are already beginning to see results that convince us we are on the right track.

MODERNIZATION FILM

And now for a film report that will give you a graphic look at what I have talked about. Since it includes a set of concluding remarks, let me say at this point how much I enjoyed the opportunity to be here with you and to share some of the work we are engaged in to achieve NEW HORIZONS IN THE FIELD OF EXPLOSIVES --- and to make the point that SAFETY IS GOOD BUSINESS. Thank you.

FILM ON - 21 MINUTES

VUGRAPH SUMMARY

1 - Batch Method Vs Continuous Process Handling
2 - Batch Vs Continuous Process Facility Requirement
3 - Cost, Personnel, and Equipment Comparison
4 - Safety Comparison

5 - Conventional Melt Pour Facility
6 - Comparison of Batch Vs Continuous Melt Pour Processes
7 - The Automated Melt Pous Process
8 - The Detonation Trap Approach
9 - Prototype Detonation Trap Mod III

10 - Riser Scrap Recovery
11 - Continuous Riser Melter

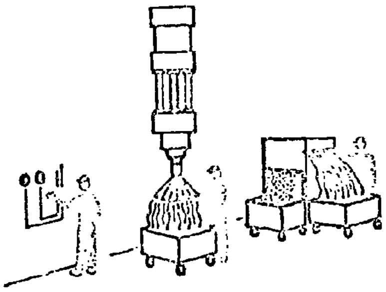
12 - Zone Cooling Method

13 - Manual 105MM Propellant Charge Loading & Assembly
14 - Weighing Operation
15 - Manual Bag Loading
16 - Automated 105MM Propellant Charge Loading & Assembly System

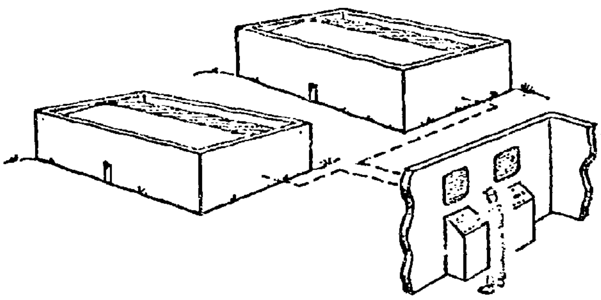
BENEFITS

Safety:

Reduced Personnel Exposure



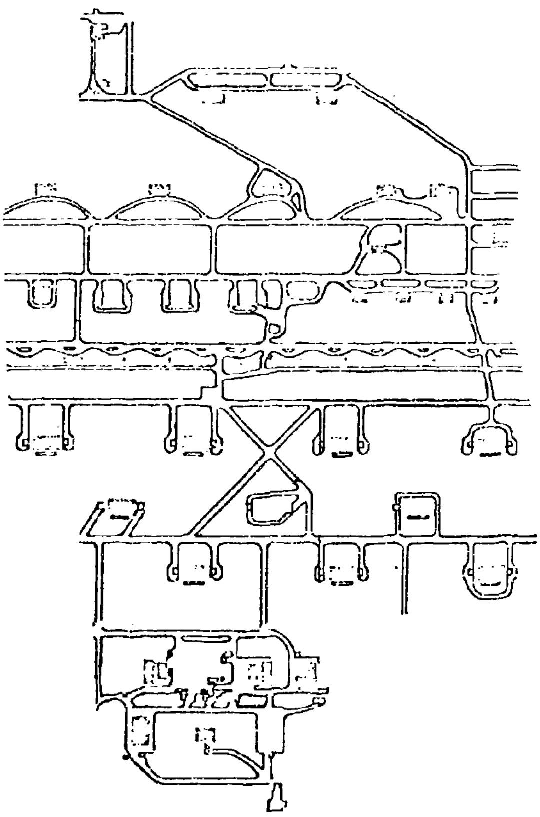
BATCH



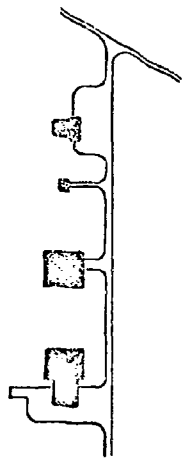
CONTINUOUS

Reduced Capital Investment:

Fewer Buildings, Less Land & Roads



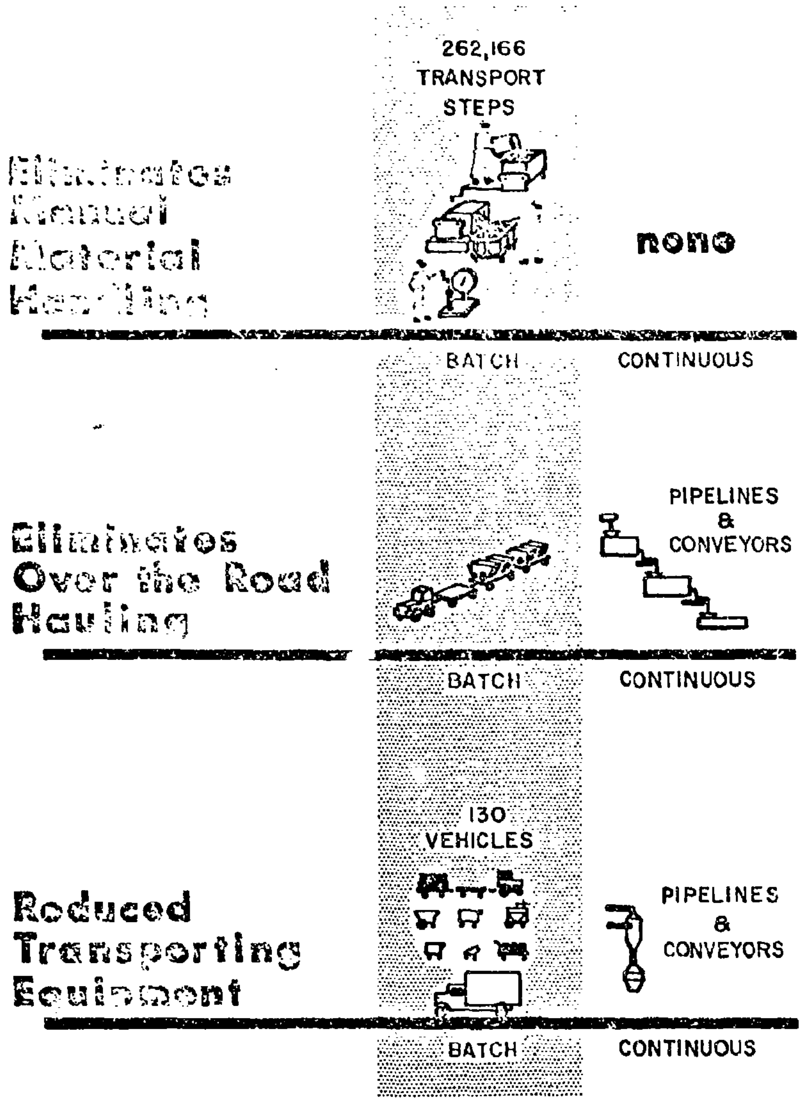
BATCH

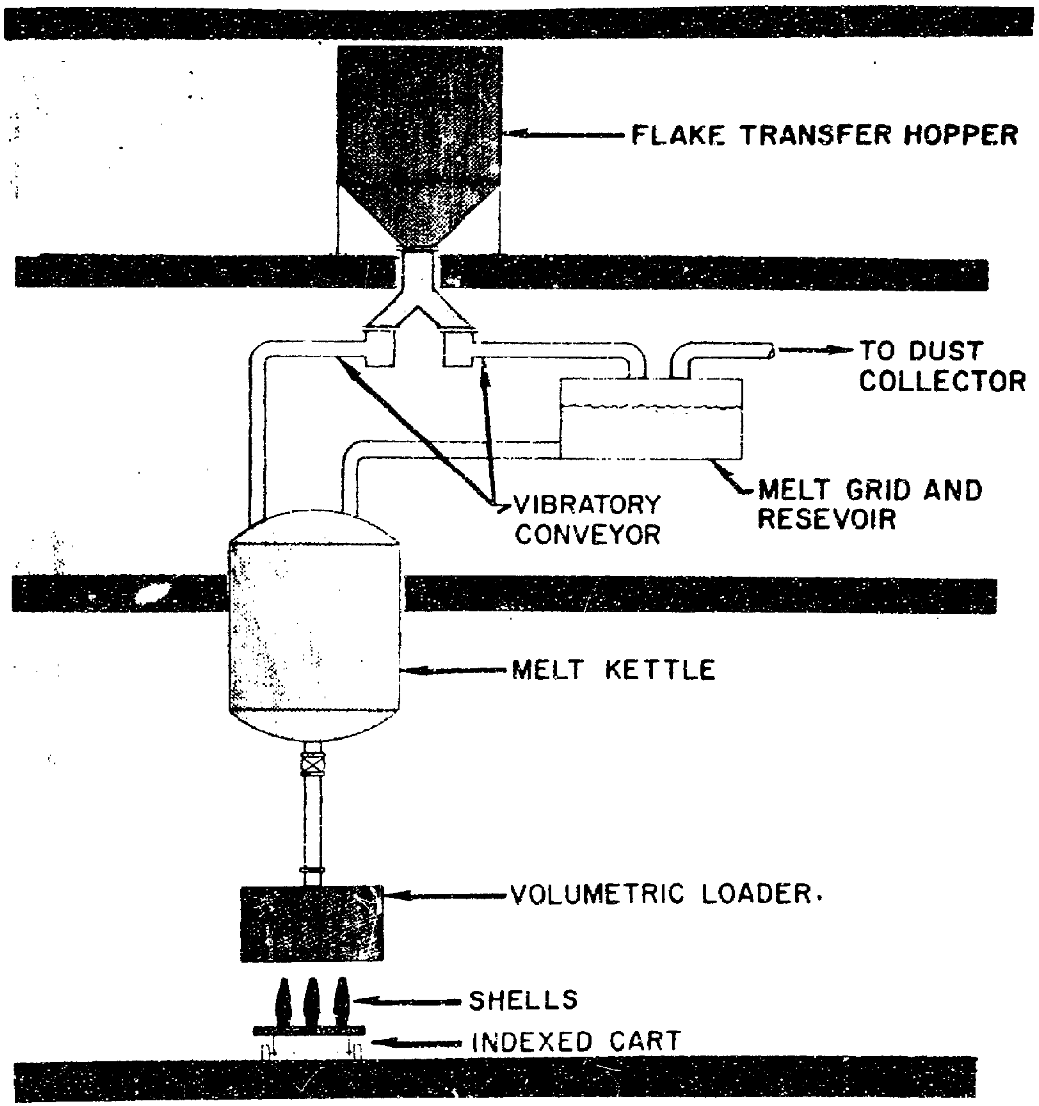


CONTINUOUS

MORE BENEFITS

	BATCH	CONTINUOUS
Reduced Manufacturing Cost per Lb.	51¢	38¢
Fewer Personnel	524	96
Less Operating Equipment	130 ITEMS	53 ITEMS


262,166
TRANSPORT
STEPS
none
BATCH
CONTINUOUS
Eliminates
Over the Road
Hauling
PIPELINES
&
CONVEYORS
BATCH
CONTINUOUS
Reduced
Transporting
Equipment
130
VEHICLES
PIPELINES
&
CONVEYORS
BATCH
CONTINUOUS

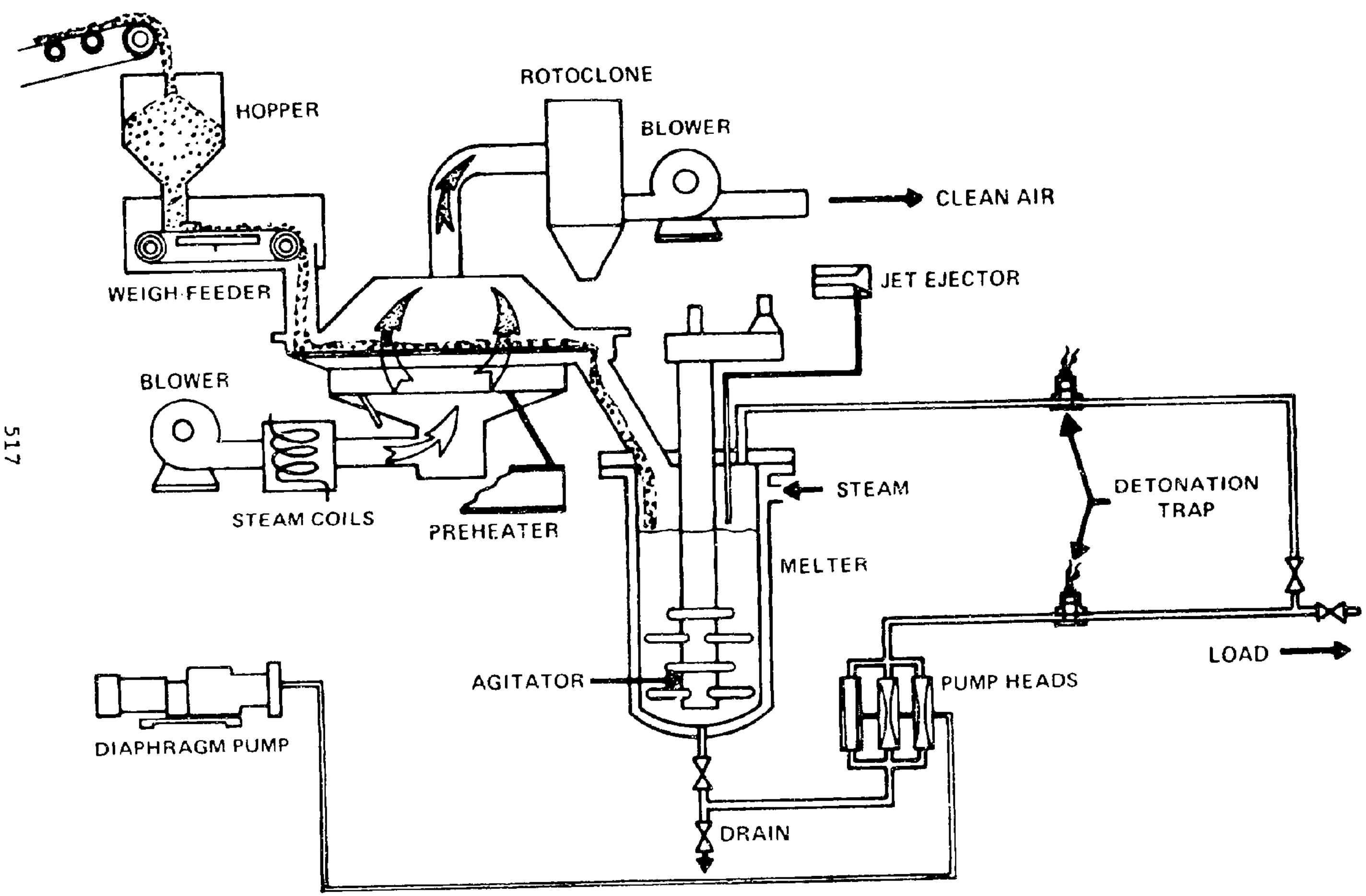


PRESENT MELT - POUR PROCESS

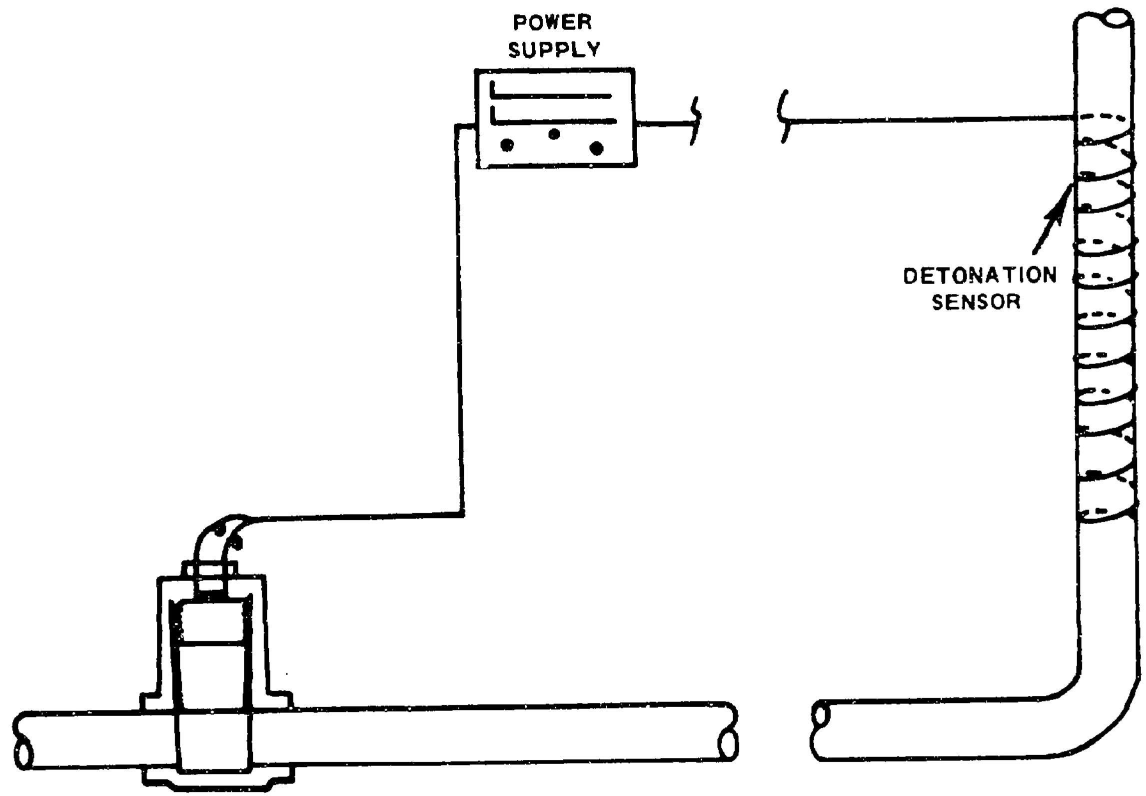
MELT POUR PROCESS

	EXISTING PLANTS	MODERNIZED PLANTS
PROCESS TYPE	BATCH MANUAL	CONTINUOUS AUTOMATED
EXPLOSIVE IN PROCESS, LB	40,000	2,000
RATE LB/H	9,000	9,000
PERSONNEL (DIRECT EXPOSURE) APPROX	12	

EQUIPMENT FLOW SHEET OF AUTOMATED MELT-POUR PROCESS PLANT

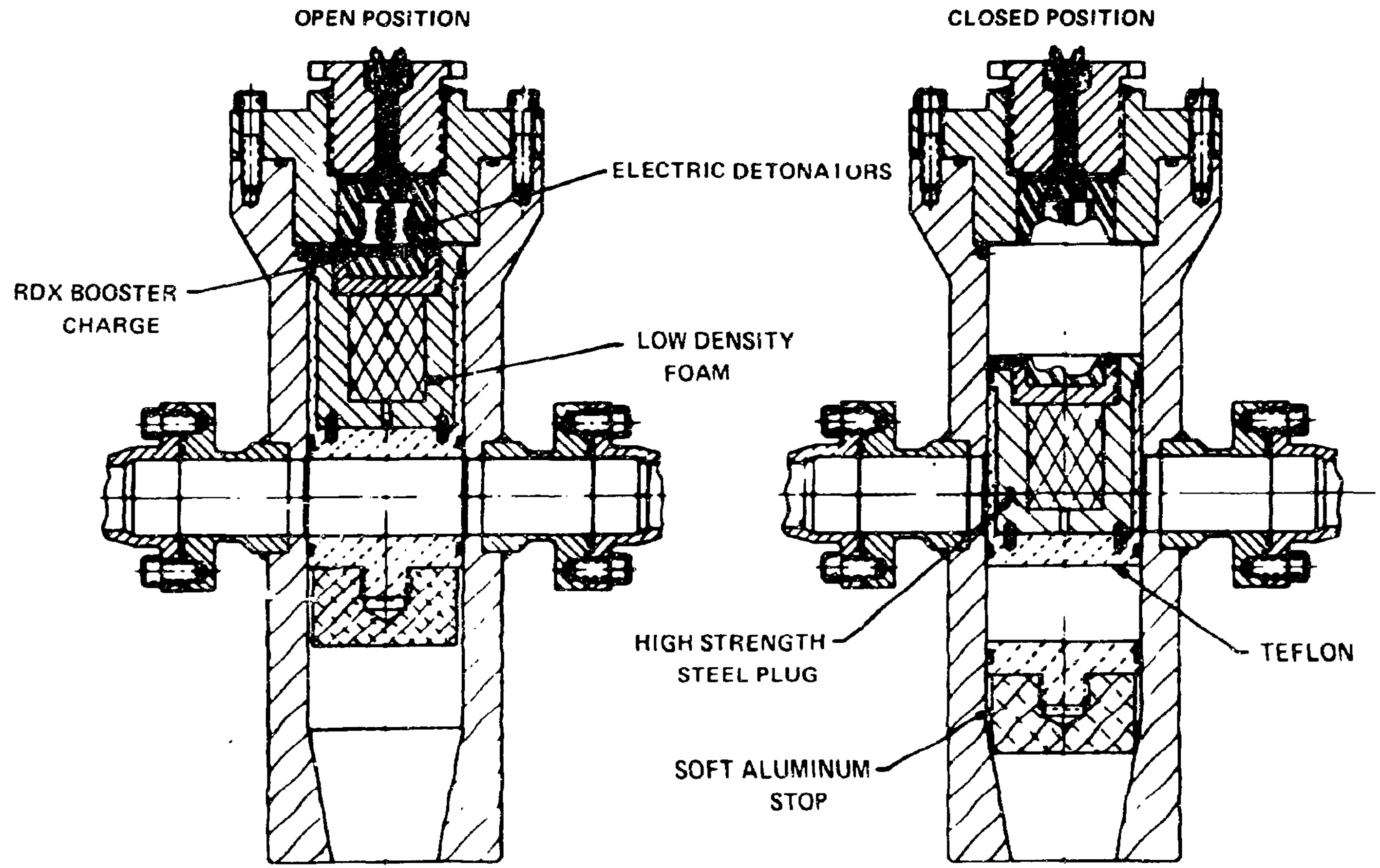


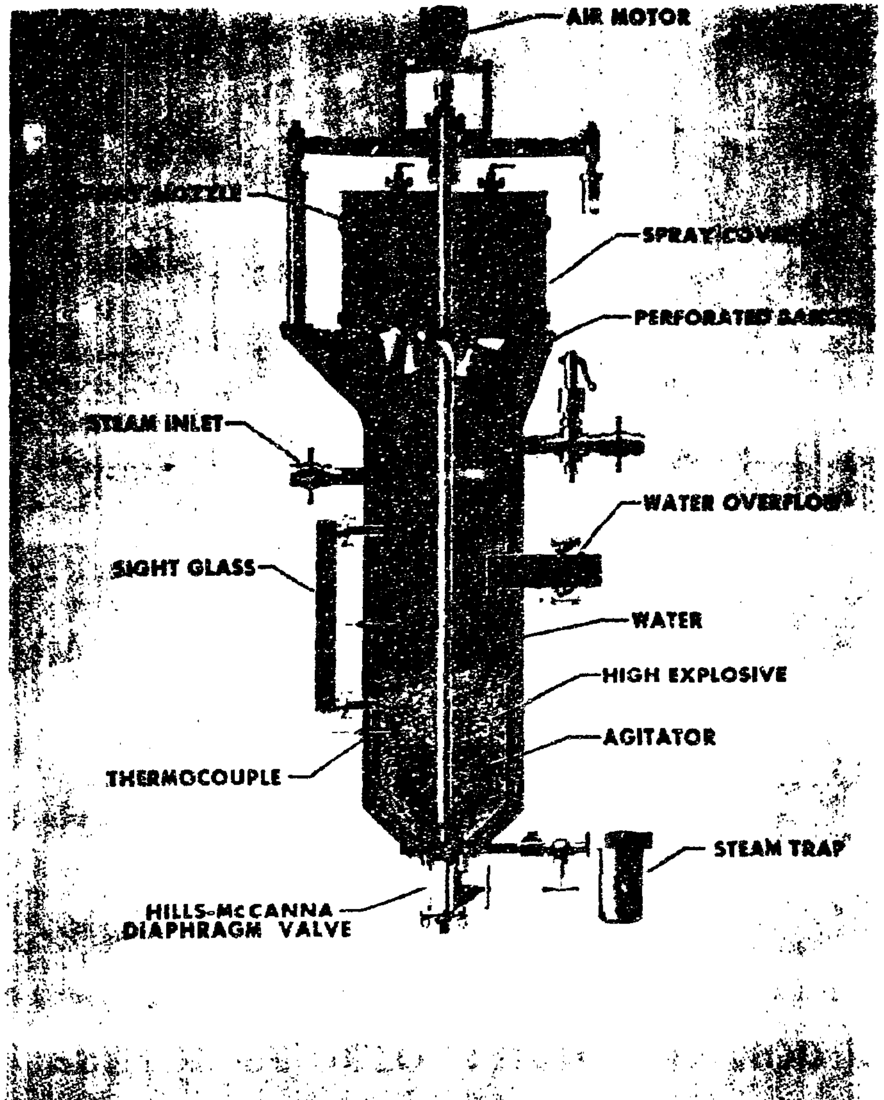
DETONATION TRAP APPROACH



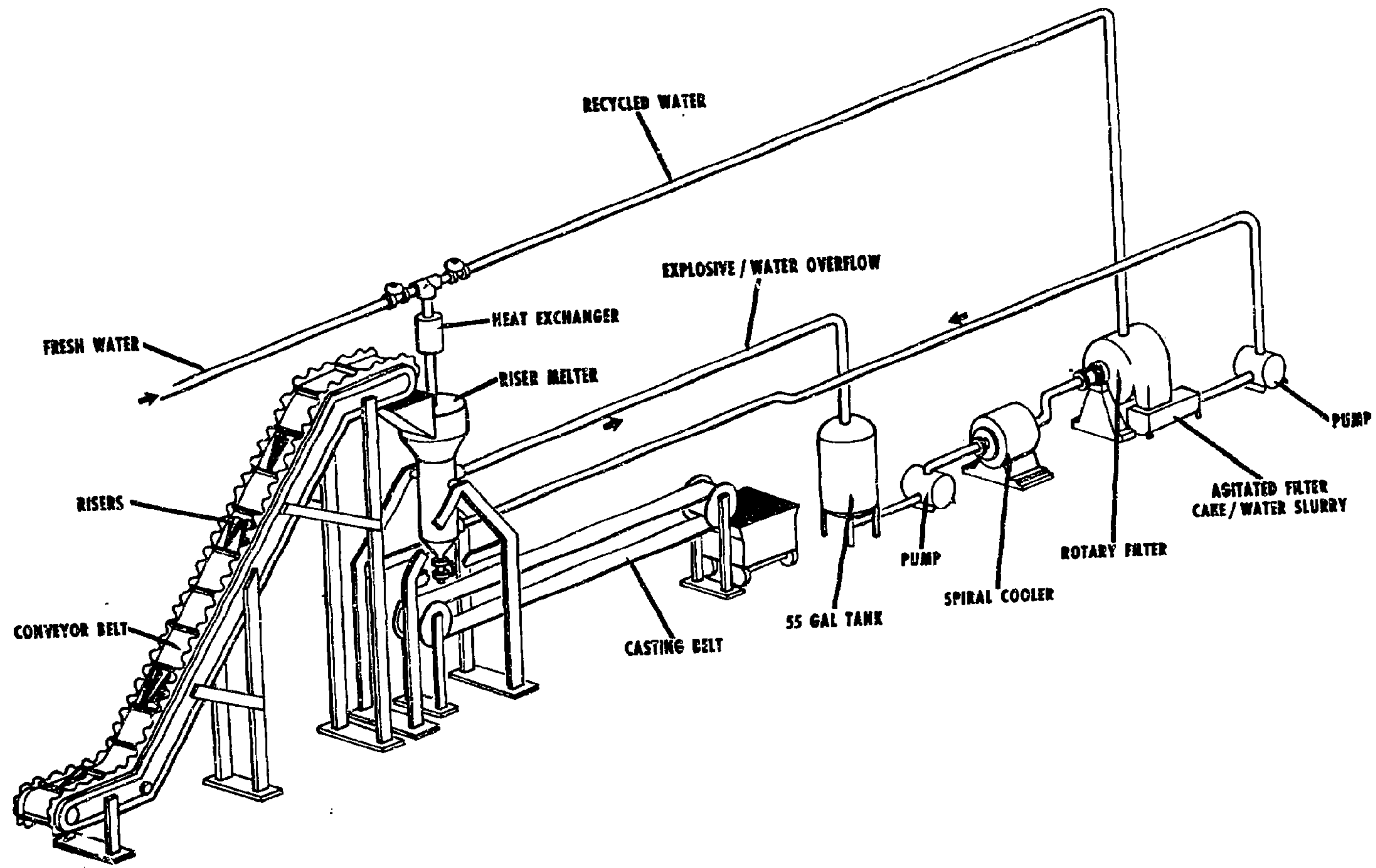
LRPL-AED
PICATINNY ARSENAL

PROTOTYPE DETONATION TRAP MOD III



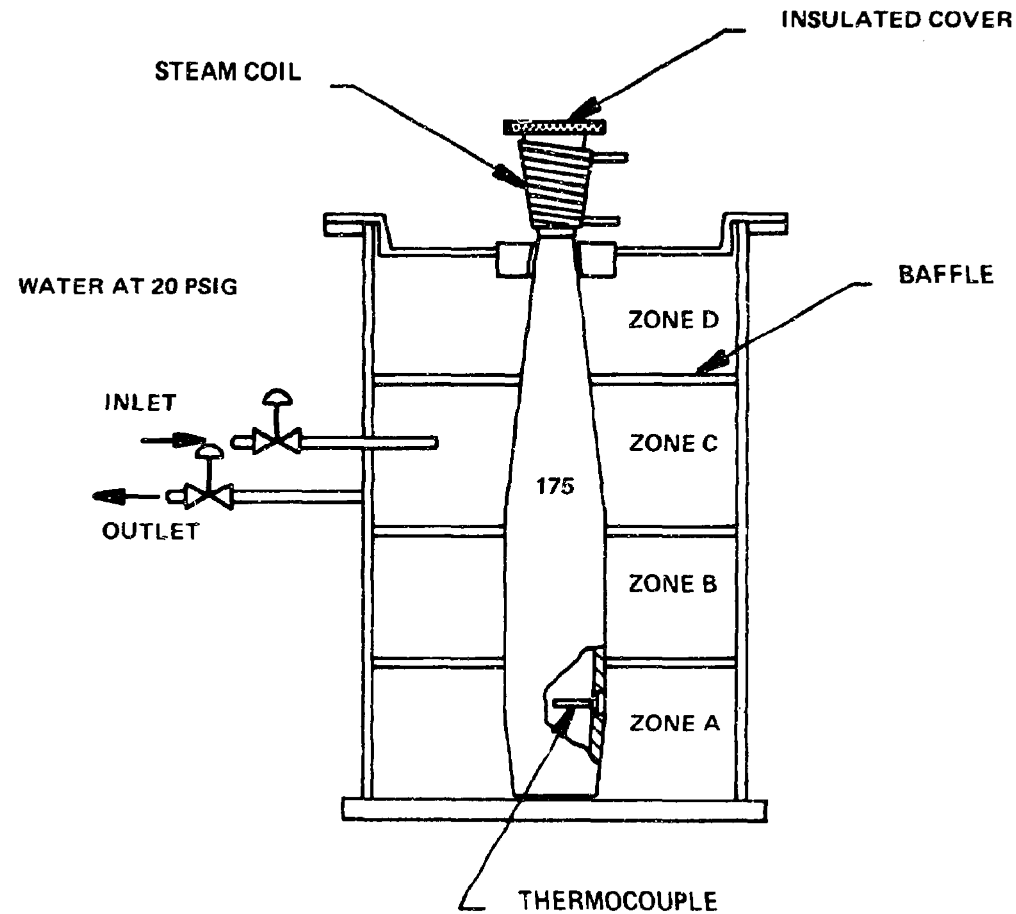


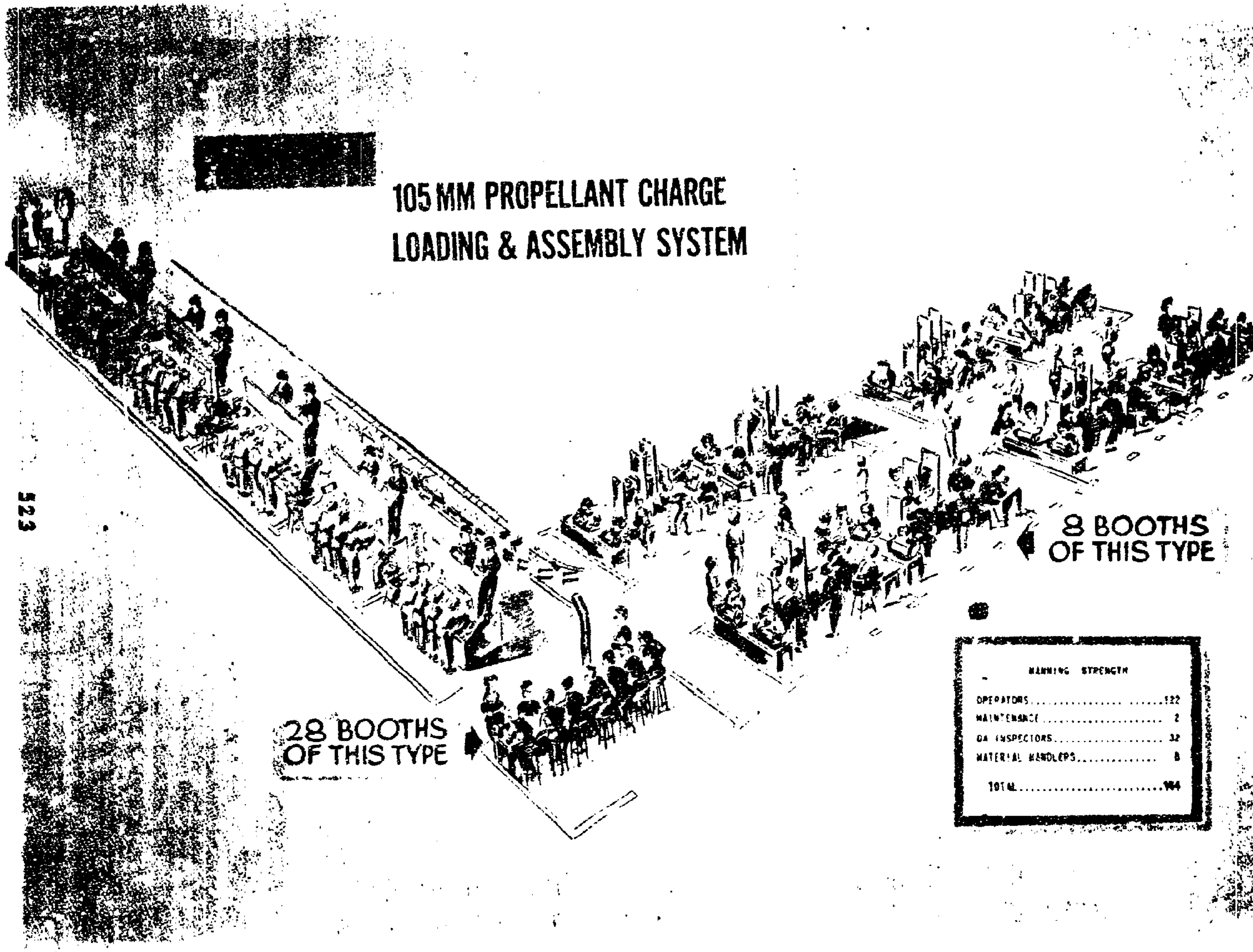
RISER SCRAP REWORK SEPARATOR



CONTINUOUS RISER MELTER

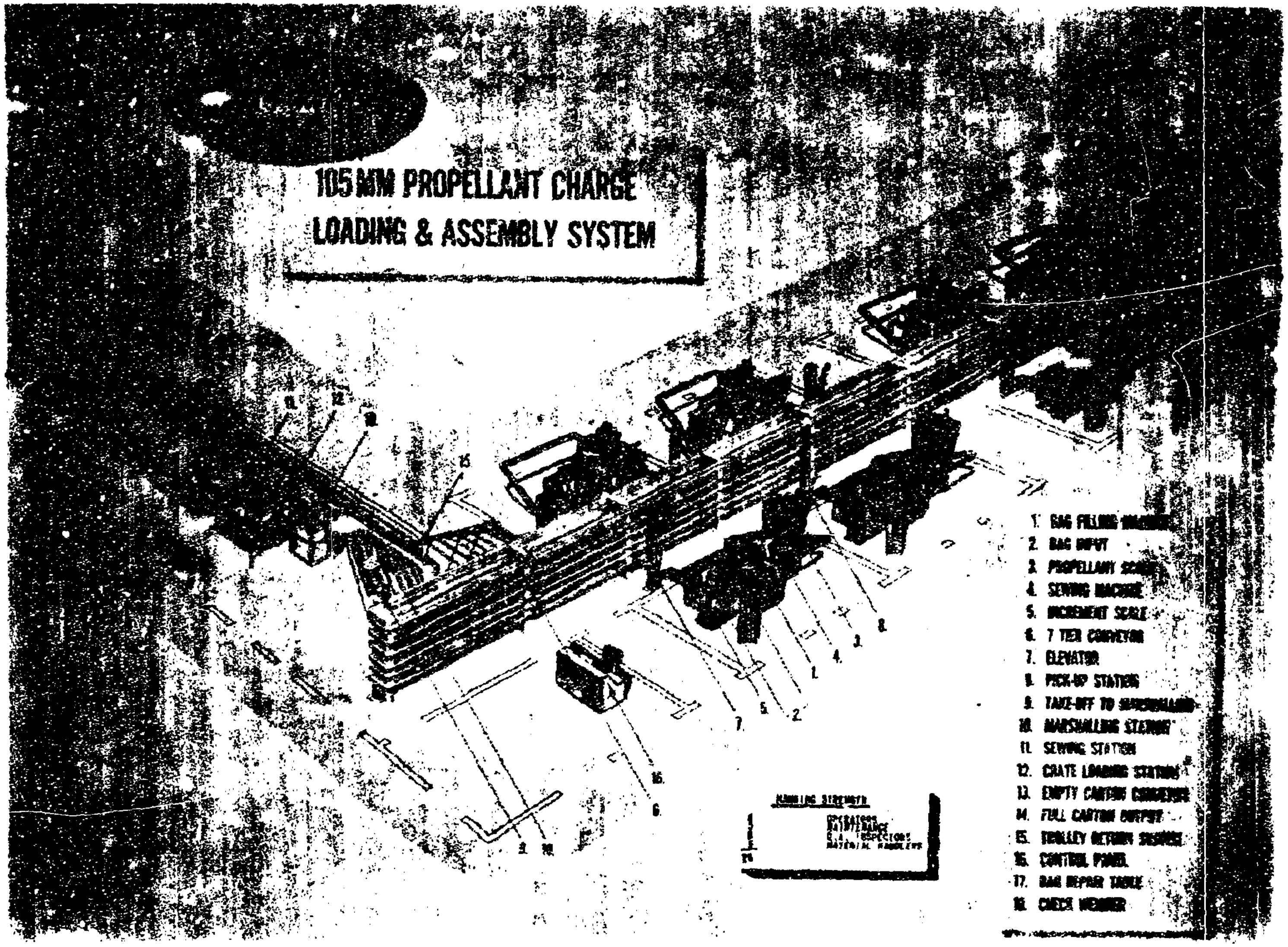
MULTI- ZONE CONTROLLED COOLING FOR 175MM PROJECTILE - COMP B LOADED




105 MM PROPELLANT CHARGE
LOADING & ASSEMBLY SYSTEM
8 BOOTHS
OF THIS TYPE
28 BOOTHS
OF THIS TYPE
MANNING STRENGTH
OPERATORS........................122
MAINTENANCE..........................2
QA INSPECTORS......................32
MATERIAL HANDLERS.................8
TOTAL..............................164


LIMITATIONS
EXPLOSIVES
INCR 150
IGN. NA.
PERSONNEL
OPERATORS
TRANSIENTS 3


2



105MM PROPELLANT CHARGE
LOADING & ASSEMBLY SYSTEM
1. BAG FILLING
2. BAG INPUT
3. PROPELLANT
4. SEWING MACHINE
5. INCREMENT SCALE
6. 7 TIER CONVEYOR
7. ELEVATOR
8. PICK-UP STATION
9. TAKE-OFF TO
10. MARSHALLING STATION
11. SEWING STATION
12. CRATE LOADING STATION
13. EMPTY CARTON
14. FULL CARTON OUTPUT
15. TROLLEY RETURN
16. CONTROL PANEL
17. BAG REPAIR TABLE
18. CHECK WEIGHER

MATHEMATICAL EVALUATIONS FOR CONTROLLING HAZARDS

By:
William T. Fine
Chief, Safety Department
Naval Ordnance Laboratory
Silver Spring, Maryland 20910

ABSTRACT: To facilitate control of hazards, two of the principal needs are for the following:

1) a method to "calculate the risk" due to a hazard, and obtain an actual determination of the seriousness of the hazard. This provides a logical system for assigning priorities for preventive effort.

2) a method to determine whether the estimated cost of contemplated corrective action to alleviate a hazard is justified.

To supply these needs, a formula has been devised which weighs the controlling factors and calculates the risk of a hazardous situation, giving a "Risk Score" to the urgency for remedial attention. Calculated Risk Scores may then be used to establish priorities for corrective effort. An additional formula weighs the estimated cost and effectiveness of any contemplated corrective action against the Risk Score and gives a determination as to whether the cost is justified. Specific examples are given.

MATHEMATICAL EVALUATIONS FOR CONTROLLING HAZARDS

I. INTRODUCTION

1. The person responsible for safety of an organization usually knows of many hazardous situations within that organization at any one time. But he can not possibly get to work on every situation immediately. He needs a method to determine just how serious each hazard is, and just what proportion of his time and effort should be devoted to each situation. In other words, he needs a priority system for his own time and effort.

2. Another closely related problem deals with economics. We sometimes have to prove that Safety is good business. When Safety comes up with a proposed remedy for a hazard, it may be necessary to convince Management that the cost of the corrective action is really justified. Most budgets are limited. Unfortunately in many cases, the decision to undertake a costly project depends to a great extent on the salesmanship of Safety personnel. As a result, due to a poor selling job, an important safety project may not be approved; or due to excellent selling by Safety, a highly expensive project may get approval when the risk really does not justify it.

3. In this report, I am presenting an easy way to "calculate the risk" due to a hazard. By using a formula, we evaluate the relative severity or importance of the hazard. This establishes priorities for attention to hazards, and guidance for Safety personnel in deciding where to concentrate their efforts. A further formula gives a determination as to whether or not the cost of proposed corrective action is justified. Use of this formula will provide solid foundation for recommendations.

II. Let us first discuss the formula for calculating the seriousness of the risk due to a recognized hazard.

1. We arrive at a numerical evaluation by considering three factors, the consequences of a possible accident due to the hazard, the exposure, and the probability that the consequences will occur. I shall explain the formula and give several actual examples of its calculation and uses.

2. THE RISK FORMULA is as follows:

Risk Score = Consequences x Exposure x Probability

Abbreviated: R = C x E x P

It is pointed out that the numerical ratings or weights assigned to each factor are arbitrarily assigned and flexible, based on the judgement and experience of the investigator making the calculation. Now let us review this formula.

3. The first element is CONSEQUENCES.
We define consequences as the most probable results of a potential accident due to the hazard we are concerned with. (injuries and property damage). Numerical ratings are assigned for the most likely consequences of an accident, from 100 points for a catastrophe down through various degrees of severity to 1 point for a minor cut or bruise. In each case, the rating would be based on your judgement as to the most likely consequences.

Degree of Severity of Consequences	Rating
a. Catastrophe: numerous fatalities; extensive damage (over $1,000,000); major disruption	100
b. Several fatalities; damage $500,000 to $1,000,000	50
c. Fatality; damage $100,000 to $500,000	25
d. Extremely serious injury; (amputation, permanent disability); damage $1,000 to $100,000	15
e. Disabling injuries; damage up to $1,000 . . .	5
f. Minor cuts, bruises, bumps; minor damage . .	1

4. The next factor is EXPOSURE.
This is defined as the frequency of occurrence of the hazard-event, (the hazard-event being the first undesired event that could start the accident sequence). We rate the frequency at which the hazard-event occurs, from continuously with 10 points, through various lesser degrees down to 0.5 for extremely remote.

The hazard-event occurs:	Rating
a. Continuously (or many times daily)	10

	Rating
b. Frequently (approximately once daily)	6
c. Occasionally (from once per week to once per month)	3
d. Unusually (from once per month to once per year)	2
e. Rarely (it has been known to occur)	1
f. Very Rarely (not known to have occurred, but considered remotely possible)	0.5

5. The third factor is PROBABILITY, which we define as the likelihood that, once the hazard-event occurs, the complete accident-sequence of events will follow, and this would have to be with the necessary timing and coincidence to result in the accident and consequences. The ratings go from 10 points if the complete accident-sequence is most likely and expected, down to 0.1 for the "one in a million" or practically impossible chance.

Description	Rating
The accident-sequence, including the consequences:	
a. Is the most likely and expected result if the hazard-event takes place	10
b. Is quite possible, would not be unusual, has an even 50/50 chance	6
c. Would be an unusual sequence or coincidence	3
d. Would be a remotely possible coincidence. (It has happened here)	1
e. Extremely remote but conceivably possible. (Has never happened after many years of exposure)	0.5
f. Practically impossible sequence or coincidence; a "one in a million" possibility. (Has never happened in spite of exposure over many years)	0.1

6. Now, let us take a few examples. For demonstration,

I have selected a situation involving explosives, a shop problem, and a construction situation.

a. EXAMPLE #1:

(1) Problem. Building No. 303 at the Naval Ordnance Laboratory contains a number of ovens which are used for environmental testing (heating) of explosive material with up to five pounds of high explosive material in an oven. One side of the building is made of "blow-out panels" so that in case of an accident most of the blast will be expended out the blow-out wall rather than demolish the building. This type of oven has been known to "run away" or heat excessively due to faulty heat controls and thereby cause the explosives in the oven to detonate. People walk past the outside of this building. The potential hazard considered here is the endangering of persons who occasionally walk past the building on its blow-out side.

(2) The first step in calculating the risk is to study the situation and list the most probable sequence of events for an accident. These are as follows:

(a) Several ovens are in use, each containing explosives. This is normal.

(b) Persons are present in the area outside the building on the blow-out side. This is a normal and accepted condition.

(c) Now something goes wrong. The thermostat of one oven fails and the oven temperature rises above the proper operating range. (This is the hazard-event).

(d) The secondary emergency shutoff control also fails to function.

(e) The oven overheats.

(f) The explosive detonates.

(g) A passerby near the building is fatally injured by flying debris.

That is the complete sequence.

(3) Now we consider the formula use:

Risk Score = Consequences x Exposure x Probability

(a) First we select the rating for the most probable CONSEQUENCES. In this case we decided that a fatality was the most likely consequence for us to consider. That is item "c" on the rating chart, with a rating of 25. Therefore CONSEQUENCES = 25.

(b) Next we evaluate the EXPOSURE. For the exposure, the hazard-event is the failure of the thermostat. This has happened before, but very "rarely." That would be "e" on the rating chart. Therefore EXPOSURE = 1.

(c) Next we consider PROBABILITY. This depends on judgement, experience and studied opinion. We decide here on what the probability is that the complete accident-sequence will follow the hazard-event. We must consider each step in the sequence. We consider that all ovens have been equipped with secondary emergency shutoff controls. Thorough maintenance procedures ensure the proper functioning of both the thermostatic controls and the emergency shutoff controls. We would consider failure of either set of controls quite unlikely. So for both sets to fail at the same time and on the same oven, it would be considered a very remotely possible coincidence. Therefore the PROBABILITY rating is remotely possible, item "d" on the rating chart. Therefore PROBABILITY = 1.

(d) Substituting in the formula:

Risk Score = 25 x 1 x 1 = 25

Now the significance of this Risk Score of 25 cannot be seen until we compute the Risk Scores for other hazards using the exact same criteria and judgement and have a basis for comparison.

b. EXAMPLE #2:

(1) Problem. Six compressed oxygen cylinders are standing unsupported on a pallet in the shop next to a busy aisle; caps are on securely. In this case, we consider that there are two hazards:

Hazard (1): A cylinder could topple and cause a foot injury.

Hazard (2): A cylinder could topple, rupture and become a missile.

(2) Since there are two hazards, each one is evaluated separately and their Risk Scores added.

(3) Evaluating Risk Score for Hazard No. 1, the foot injury hazard:

(a) The accident sequence is:

1 Condition as stated above.

2 Shop trucks, carts and pedestrians pass close by many times daily, often brushing against cylinders. This is the hazard-event.

3 A person bumps a cylinder hard enough to cause it to topple over.

4 Cylinder falls on the man's foot.

5 A disabling injury results: fractured bones in the foot.

(b) We now apply the formula:

1 CONSEQUENCES are a disabling injury, "e" on the rating chart. C = 5 points.

2 For the EXPOSURE or the Frequency of the hazard-event; persons brushing against or bumping a cylinder occurs many times per day. That is "a" on the rating chart. Therefore E = 10.

3 For PROBABILITY, we estimate the likelihood, step by step, of all events occurring to include the fractured foot. Our reasoning follows: once a cylinder has been bumped, it is quite possible that one will topple over: ("b" on the rating chart). It is also possible, but slightly unusual that it would land on a man's foot: that would be "b" to "c" on the rating chart. But if it did land on his foot, a fracture is most likely. That is "a". Putting these together, we consider that the net likelihood of this series of events occurring as being "quite possible", not unusual, somewhere between "b" and "c" on the rating chart. Therefore, we interpolate and say P = 4.

(c) Now we substitute in the formula. The calculation for the Risk Score for the oxygen cylinders, foot

hazard is:

Risk Score = 5 x 10 x 4 = 200.

(4) Next we evaluate the Risk Score for Hazard No. 2, the missile hazard.

(a) Accident sequence:

1 Condition is as stated above.

2 Shop trucks, carts and pedestrians pass close by many times daily, often brushing against cylinders. That is the hazard-event.

3 A person bumps a cylinder and it topples over.

4 Cylinder ruptures or the valve is broken off, escaping compressed gas causes missile action.

5 Very serious injury occurs.

(b) Use of the formula:

1 First consider the CONSEQUENCES. We would expect a very serious injury, "d" on the chart. So C = 15.

2 Next the EXPOSURE. This is the same as for the foot hazard: the hazard-event, bumping a cylinder occurs several times daily. E = 10.

3 Next, consider the PROBABILITY that a missile and very serious injury will result. Toppling over is quite possible, but a topple should not ordinarily cause a rupture, and cylinders have protective caps. So the tank rupturing is remotely possible, or "d" on the rating chart. But in event of a rupture, missile action and a very serious injury could easily follow, "b". Therefore we consider the net probability that the serious injury will occur is "remotely possible." P = 1.

4 Substituting in the formula:

Risk Score = 15 x 10 x 1 = 150

5 Adding the Risk Scores of the two hazards, Total Risk Score = 200 + 150 = 350.

c. EXAMPLE #3:

(1) Problem. A 12,000 gallon propane storage tank is located close to operations involving ultra-highly compressed air lines and equipment. Air and nitrogen at 15,000 psi. A high pressure pipeline explosion could result from a malfunctioning safety valve, a human error in operating the equipment, or damage to a pipeline. Blast or flying debris could then strike the propane storage tank, rupture it and cause it to explode with the consequences of several fatalities and building damage up to $500,000.00. We know this kind of accident can happen, because it did a few years ago.

(2) Sequence of events:

(a) Normal activities involve operation of equipment and pressurizing of pipelines in the vicinity of the propane storage tank.

(b) A 3000 psi pipeline 50 feet away from the storage tank becomes damaged and unnoticed. (This is the hazard-event.)

(c) The pipeline bursts.

(d) Metal debris from the blast strikes the propane tank with such force that the tank is ruptured.

(e) Propane leaks out of the tank.

(f) A spark ignites the propane fumes.

(g) The propane and air mixture explodes.

(h) Building damage is $500,000 and two men are killed.

(3) Next we determine values and substitute in the formula.

(a) CONSEQUENCES: Two fatalities and damage loss of $500,000. C = 5.

RISK SCORE SUMMARY AND ACTION SHEET

HAZARD DESCRIPTION	RISK SCORE	ACTION
Window washer on third floor, without safety belt, hangs on with one hand and leans out	1500	
Men working in ditch six feet deep, ditch not shored, dirt is soft, subject to sliding	750	
Painters on scaffold without handrail, 30 feet high, not using safety belts	750	
Benzene used for cleaning floor of shop, a busy area, men smoke, other spark sources nearby	450	Immediate correction required. Activity should be discontinued until hazard is reduced.
Compressed flammable gas cylinders standing unsecured on pallet, along busy aisle, caps on	375	
Uncontrolled compressed air used in machine shop, up to 90 psi, for general cleaning	300	
Men smoking in flammable storage warehouse, no sprinkler system, highly flammable material	270	
Portable electric drill in use without ground wire, getting rough usage by several people	200	
Compressed air receiver without safety relief valve, automatic shut-off at 200 psi, old equipment	180	
People walking past deep unguarded ditch, considerable traffic, poor lighting	150	Urgent. Requires attention as soon as possible.
Heavy instruments unstable on seven foot high shelf case, subject to bumping by employees	150	
Trucks rounding blind corner without stopping, opposing traffic and pedestrians, 10 MPH limit	135	
Steps of main building slippery whenever wet, no handrail, many pedestrians daily	90	
Compressed oxygen cylinder standing unsecured near wall, little traffic or movement	85	
Pedestrian and hand-cart traffic at blind corner in hallway of shop building	60	
Oxygen and acetylene cylinders stored together, caps on, good ventilation, fireproof surroundings	45	
Inadequate handrailing along outside stairway, occasional use every day	40	
Large propane storage tank in busy area: vehicle traffic, and high pressure air operations	37.5	
Both pedestrians and vehicles using same road. Road not always wide enough for both	37.5	Hazard should be eliminated without delay, but situation is not an emergency.
Chemicals stored in nonsparkproof refrigerators, occasionally including flammable volatile liquids.	30	
Broken sidewalk, occasional pedestrian traffic, holes and loose concrete	30	
Persons near explosives building, within range of possible missiles; safe procedures in building	25	
Portable vacuum pump lacking belt guard. Pump moved around occasionally by several employees	18	
Machinist using heavy file without file handle, in daily use	18	
Workman using hammer with loose head, in use daily for odd jobs	18	

Illustration 1

(b) EXPOSURE: High pressure air lines have been known to have been neglected or damaged. Frequency of such occurrences is considered "unusual." This is "d" on the rating chart. Therefore E = 2.

(c) PROBABILITY: Now we estimate the likelihood that a damaged pipeline will explode and the explosion will occur close enough and with enough blast to throw debris and strike the propane tank with such force as to complete the accident sequence. Several pipeline bursts have occurred in past years, but none have damaged the propane tank. Just a few of the pipelines are considered close enough to endanger the tank. After careful observation, the complete accident sequence is considered very remotely possible. This is "e" on the rating chart, and the rating is placed at P = 0.5.

(d) Substituting into the formula:

$$R = 50 \times 2 \times 0.5 = 50$$

7. SUMMARIZING RISK SCORES. In the same manner as demonstrated, the Risk Scores for other hazardous situations have been calculated. These cases are now listed in order of their Risk Scores, or we can say - in order of the relative seriousness of their risks, on a "Risk Score Summary and Action Sheet."

Illustration: Risk Score Summary and Action Sheet

Note the two horizontal lines on the right side of the chart. Above the upper horizontal line are the hazards with the highest Risk Scores, down to a Risk Score of 180. The line was drawn here because it was adjudged that for these risks, corrective action was required immediately, and any operation must be stopped until the score was lowered. The middle section of the chart contains the hazards considered somewhat less urgent but still requiring attention as soon as possible. The hazards listed below the lower horizontal line are lesser ordinary hazards that should be eliminated without undue delay, but not as emergency situations.

8. RESULTS AND USES OF SUMMARY OF RISK SCORES.

a. The Risk Score Summary and Action Sheet is now a very useful device. It:

(1) Establishes priorities for attention by both

Safety and Management since hazards are listed in order of their importance. The position on the list of any item can be lowered by corrective action which will decrease any one of the factors; Consequences, Exposure, or Probability.

(2) Provides guidance to indicate urgency of newly discovered hazards. For each new hazardous situation, compute the Risk Score. Its urgency is indicated by the ACTION area in which its Risk Score falls. For example, it would serve as backing if you felt that a job must be stopped when a highly hazardous situation is noted in a highly essential operation.

III. FORMULA TO DETERMINE JUSTIFICATION FOR RECOMMENDED CORRECTIVE ACTION.

1. Next we go to an addition to the Risk Score formula as a method of determining whether the cost of corrective action to alleviate a hazard is justified. Once a hazard has been recognized appropriate corrective action must be tentatively decided upon and its cost roughly estimated. Now a formula is used to determine whether the estimated cost is justified.

2. THE FORMULA is as follows:

$$\text{Justification} = \frac{\text{Consequences} \times \text{Exposure} \times \text{Probability}}{\text{Cost Factor} \times \text{Degree of Correction}}$$

Elements are abbreviated: $J = \frac{C \times E \times P}{CF \times DC}$

It should be noted that the elements of the numerator of this formula are the same as in the Risk Score formula. We have simply added a denominator made up of two additional elements: Cost Factor and Degree of Correction.

3. COST FACTOR CF is a measure of the estimated dollar cost of the proposed corrective action. Ratings are as follows:

Cost	Rating
a. Over $50,000	10
b. $25,000 to $50,000	6

Cost		Rating
c.	$10,000 to $25,000	4
d.	$1,000 to $10,000	3
e.	$100 to $1,000	2
f.	$25.00 to $100	1
g.	Under $25.00	0.5

4. DEGREE OF CORRECTION is an estimate of the degree to which the proposed corrective action will eliminate or alleviate the hazard. Its ratings are as follows:

Description		Rating
a.	Hazard positively eliminated, 100%	1
b.	Hazard reduced at least 75%, but not completely	2
c.	Hazard reduced by 50% to 75%	3
d.	Hazard reduced by 25% to 50%	4
e.	Slight effect on hazard (less than 25%)	6

5. CRITERIA FOR JUSTIFICATION. To use the formula, values are substituted into the formula to determine the numerical value for Justification. This will usually come out between 1 and 50. The Critical Justification Rating has been arbitrarily set at 10. For any rating over 10, the expenditure will be considered justified. For a score less than 10, the cost of the contemplated corrective action is not justified.

6. EXAMPLES. For demonstration, we will continue the same examples already discussed.

a. Example of the hazard to persons near a building in which explosives are processed. The corrective action

that was proposed was the construction of a barricade along the outside of the building to protect passersby in event of an explosion within. The estimated cost was $5,000.00. Using the "J" formula:

(1) The Consequences, Exposure, and Probability as already discussed were evaluated at 25, 1, and 1 respectfully.

(2) Cost Factor. Estimated cost is $5,000.00. Therefore, based on the CF Rating Chart, CF = 3.

(3) Degree of Correction. The effectiveness of the barricade to protect passersby is considered to be over 75 percent. Therefore DC = 2.

(4) Computation: $J = \frac{25 \times 1 \times 1}{3 \times 2} = \frac{25}{6} = 4.20$

(5) Conclusion. The expenditure of $5,000.00 to construct a barricade to protect passersby is well below 10, and therefore is not justified.

(6) Further consideration. Since the Risk Score is 25, this situation still requires attention. Review of this problem revealed that other steps could be taken to lower the risk. The Probability of the complete accident sequence occurring was considered to be remote, but it could be made much more remote (and the Risk Score halved) by administrative controls such as portable barriers and warning signs, to reduce or even eliminate the presence of passersby in the danger zone.

b. For the next example, consider the hazardous location of the 12,000 gallon propane storage tank. The proposed corrective action was to relocate the tank underground in a place where it would be less likely to be damaged by any external source, at an estimated cost of $28,000.

(1) Determine the values for elements of the formula:

(a) Consequences x Exposure x Probability were already determined to be 50 x 2 x 0.5, or 50. We must now divide this by the Cost Factor x the Degree of Correction.

(b) Cost Factor. Cost of relocation is $28,000. Therefore CF = 6.

(c) Degree of Correction. In the underground location there is considered no possibility of damage to the tank. Therefore DC = 1.

(d) Substituting in the formula:

$$J = \frac{50 \times 2 \times 0.5}{6 \times 1} = \frac{50}{6} = 8.3$$

(2) Conclusion. Based on our established criteria, the cost of relocation of the tank is not justified.

(3) It is emphasized that we do not say that the hazard is of little or no significance. The Risk Score is 50, and this is of appreciable concern. We must endeavor to reduce the risk, by devising other less costly corrective action, or by reducing either the Exposure or the Probability. In this case it was decided that a steel plate barrier could be erected to protect the tank from the compressed air activities at a cost under $1,000. This brings the Cost Factor down to 2. But since this action does not completely eliminate the hazard, the Degree of Correction is 2. Now we compute the Justification with these values:

$$J = \frac{50 \times 2 \times 0.5}{2 \times 2} = \frac{50}{4} = 12.5$$

The cost of this engineering action is considered justified.

(4) One tremendous benefit of the use of this formula must now be apparent, and that is in how it will really save money. Immediately after a very serious accident occurs, let us say a multiple fatality, there is a tendency for the top levels to "panic" or go to extremes in favor of safety. Perhaps as some form of self defense, managers and Commanders direct all kinds of measures regardless of cost and practicability, often excessive measures. This is not good for safety, because when situations cool down and people again become rational and reasonable, the poor judgement of such projects is apparent. Under such circumstances when costly projects are under consideration, the Justification formula can show whether or not the measures are justified, logically and simply. Safety personnel should not blindly recommend extensive safety measures, passing the responsibility to management to decide on justification and possible funding. Safety can use this formula as a simple and positive management tool to enable management to make a proper decision.

IV. CONCLUSION

1. We have presented and discussed two systems both of which can easily be used by most anyone who has good sound judgement and experience in safety, with nominal training and guidance.

a. We discussed a formula to calculate Risk Scores, or the relative severity of hazards. Use of this formula places priorities on hazards for attention by both Safety and Management; this chart gives a quick reading or evaluation of the safety status of the organization at any time; it can show safety progress over a period of time by the number of items moved downward to lower risk levels on the chart; it gives guidance to Safety in determining where to concentrate its efforts; and it gives general guidance as to the urgency for corrective measures for any one hazard.

b. Our next system, the Justification Formula provides both Safety and Management with guidance in deciding whether the cost of a proposed project is justified. Use of this formula provides a solid foundation upon which Safety may base its recommendations for corrective action. Its use will assure management that safety projects which actually are not justified will not be recommended. It will therefore cause management to place greater faith in Safety and to give greater support to Safety. It will help to establish that Safety is not just a business, but it is a good profitable business.

SYSTEM SAFETY ENGINEERING APPLICATIONS

TO

EXPLOSIVE ORDNANCE

BY

Robert F. Sellars

System Safety Engineer

Martin Marietta Corporation

Orlando Division

Orlando, Florida
32805

SYSTEM SAFETY APPLICATIONS TO EXPLOSIVE ORDNANCE

A. Introduction

Objective. The primary objective of this paper is to present the relationship between system safety engineering and explosive ordnance to those who are not familiar with either disciplines and who do not become involved on a day-to-day basis in the handling, storage, and transportation of explosive material. Reference is made to inter-discipline relationships, applicable publications and documents, functional operational methodology, and to the basic requirements for safety in the explosive ordnance field.

General. The following discussion on system safety engineering is applicable to the safety aspects of all explosive munitions and ordnance items that can cause injury to personnel or damage to adjacent materials or to facilities. Explosive ordnance includes all ammunition, biological and chemical filters, pyrotechnics, bombs, fuzes, grenades, unguided rockets, warheads of all types, and the associated racks, ejection cartridges, guns, launchers and dispensers necessary for aircraft carriage and release; it also includes solid and liquid propellant rocket motors where these items are used in conjunction with the foregoing ordnance. In this discussion, munitions are intended for delivery by the Armed Forces in offensive and defensive operations, or for tests in connection with research and development of munitions. System safety principles also apply to hand guns, small arms, torpedoes, land and sea mines and

depth charges. Although nuclear effects are not normally considered from the explosive point of view, high explosives (HE) are of primary concern to safety; therefore, nuclear munitions must be treated in accordance with applicable safety regulations and procedures.

Background. There is a clear path of technological advance by which system safety considerations have become requirements, particularly in the area of explosive ordnance. During the early experiments with gunpowder and the development of cannon and rifles, gunners were required merely to'remain out of the line of fire and to stand clear of recoil to avoid injury. In spite of the fact that many weaponeers were unnecessarily killed and much equipment was damaged in those early days of explosives, little thought was given to the control of hazards involved because of ignorance and the comparatively low value attached to human life. Safety philosophy was based only on the fact that ordnance was dangerous and those working with explosives unavoidably accepted that danger. However, during the 15th and 16th centuries as warring European nations continued development of more powerful explosives, different types of ammunition, longer ranges and larger guns, armament leaders began to consider the safety of ordnance operations in order to increase their effectiveness, to protect operators and equipment, and to ensure victory. Since that time, the growth of safety as a functional discipline has progressed rapidly through the use of advanced techniques proposed by military engineering leaders. During the past two centuries, military advances in the uses of explosive ordnance have raised safety

engineering performance to a level that has almost guaranteed a minimum hazard to personnel and equipment if prescribed precautions, procedures, and instructions are followed. Protection afforded to a manufactured ordnance end item for inadvertent or unplanned action gradually developed into product safety, product assurance or safety assurance; these terms all included provisions for protection against personnel injury or damage to equipment. As an example, the term "explosive safety" includes taking necessary action to allow a planned explosion to occur without injuring friendly personnel or equipment. As explosive armament became a part of more sophisticated equipment and delivery vehicles the term "missile safety" came into use. On test firing ranges, missile safety can be reduced to three basic types: range safety, ground safety, and flight safety. Range safety involves both flight and ground safety in that the test range must remain in a safe status for range users. Flight safety ensures that the planned flight trajectory will be a safe one, that the vehicle is capable of being destructed at any point in the trajectory, and that the destruct mechanism will operate reliably. Ground safety involves all events, from assembly to launch, that must safely be accomplished in order to ensure a good flight. These types of safety will be further developed during the discussion on system safety test considerations.

B. System Safety Engineering

The system safety engineering function is a technical discipline that

has evolved from the term "product safety," a phrase still used to a great extent in the aerospace industry. The development of the concept leading to system safety originated in the application of common-sense safety practices to weapon systems. Because of occurrences such as the X-248 static ignition incident at Cape Kennedy in 1964 with the loss of three lives, the Apollo oxygen fire with the loss of three lives, expensive missile failures, and less costly but equally important accidents involving personnel, aerospace designers and engineers have pooled their technical resources for the elimination or minimization of the causes of accidents. The term "system safety" aptly describes the process of identifying, locating and eliminating hazards associated with technical defects and human error. With the problem expressed in this manner, the difference between industrial safety and system safety should be appreciated.

System safety must not be confused with industrial safety. System safety emphasizes the importance of locating and eliminating a hazard before dangerous conditions exist or an accident occurs. Industrial safety places its emphasis on the protection of personnel from injury or death and on investigative procedures leading to the prevention of similar accidents in the future. Industrial safety uses tools such as hard-toed shoes, safety glasses, hard hats, and procedures for attaining its objectives. System safety's tools are in the form of analyses and procedures leading to the protection of personnel, equipment and facilities from the potential effects of hazardous conditions.

During the many years of missile development, manufacturers have utilized the services of the safety divisions of their industrial relations departments to development accident prevention programs for the protection of their personnel. As technology improved, it was discovered that the end item, the product, should also enjoy protection from faults in order to perform its mission upon completion of production. Since this type of protection involves a different kind of safety than was used to protect personnel, the term "product safety" came into being. Subsequently, as we interpret such safety today, the protection of facilities was added to equipment and personnel safety, hence the origin of the term "system safety engineering." All safety engineers who are involved in the aerospace industry today are familiar with Military Specification MIL-STD-882, which contains the applicable definition of system safety: "......the optimum degree of safety within the constraints of operational effectiveness, time and cost, attained through specific applications of system safety engineering through all phases of the system." This generally accepted definition, which is the basis for the System Safety Program Plan (SSPP), provides for the acceptance of system safety engineering as a technical discipline among management functions including engineering, finance, scheduling and analysis. The term "technical" as applied to system safety engineering is very appropriate in view of the fact that system safety extends across the technical disciplines of design, engineering, research, development, test, ordnance, human factors,

value engineering, reliability, and even in maintenance. System safety design criteria state that at least two equipment failures or two operator errors, or a combination of one equipment failure and one operator error, shall be required for a critical hazard to exist. Personnel performing system safety engineering tasks such as fault hazard analysis, fault tree analysis, failure mode and effects analysis, design reviews, and specification writing must be familiar with the tools of all those trades in order to predict the existence of potential hazards and to take the necessary corrective action to prevent them from occurring. With the effective use of these tools, systems engineering achieves its goal of product safety without injury to personnel or damage to equipment or facilities while performing the assigned mission.

Other objectives of system safety engineering include the detection, identification and minimization of potential hazards to personnel, equipment and facilities. In aerospace engineering fields, these objectives are further identified with mechanical, electrical, electrostatic and explosive ordnance functions. In addition, explosive ordnance hazard characteristics for handling, storage and transportation become responsible considerations for system safety.

Safety, management, organization, administration, and methodology. Under normal project conditions, system safety engineering reports to a system engineering function in aerospace programs in a similar manner to reliability, maintainability, value engineering, and human factors.

These system support functions ensure the success of product design and development leading to a safe systems-integrated end item. A typical aerospace system safety engineering organization is shown in Figure 1.

The governing system safety engineering document is MIL-STD-882, "System Safety Program for Systems and Associated Subsystems and Equipment, Requirements for." This standard establishes the general requirements for the application of system safety engineering principles from the design phase to the conclusion of the entire system life cycle. One of the objectives of this program is to eliminate or reduce potential hazards in order to minimize the probability of damage to equipment, human injury, monetary loss, and mission degradation due to safety deficiencies.

In accordance with the requirements of MIL-STD-882, a System Safety Program Plan (SSPP) is prepared for use as directed by the procuring activity. The SSPP is a detailed plan for achieving system safety objectives. The plan lists the purpose for which it is written, defines responsibilities and authority of the system safety engineer, lists program milestones, defines safety criteria, describes the safety support activities that must be performed, and establishes reporting schedules for system safety accomplishments.

In order to determine eventually the probability of occurrence of an undesirable event or a potential hazard, the SSPP requires that several types of safety analyses be conducted. Failure Mode and Effects Analyses (FMEA) are designed to isolate those components that will fail under specific

AN AEROSPACE SYSTEM SAFETY

ENGINEERING ORGANIZATION

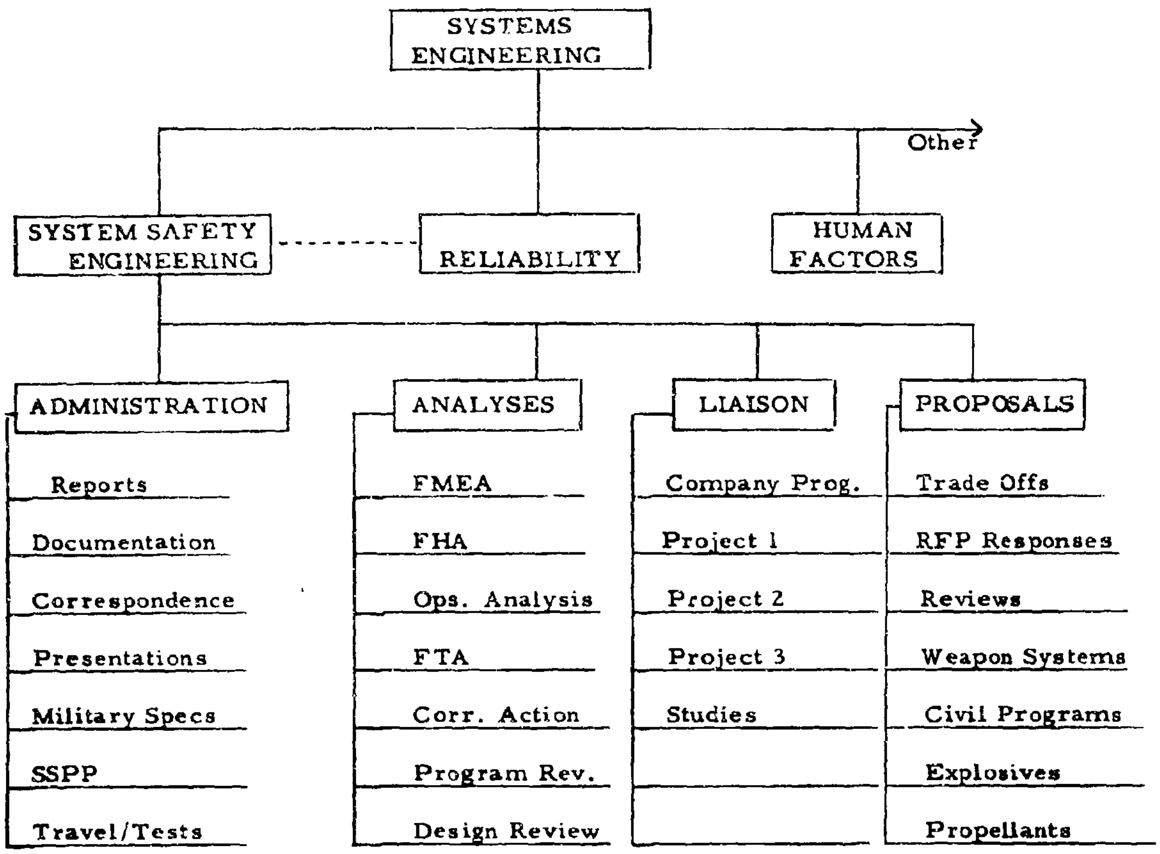


FIGURE 1

circumstances, the modes in which they are expected to fail, and the effects of the failures on other parts of the subsystem or other components. Fault Hazard Analyses (FHA) are used to evaluate component failure modes and failure rates to determine the hazard classification category of a component under prescribed conditions. Fault Tree Analyses (FTA) are conducted on systems and subsystems to determine the probability of the occurrence of an undesired event that could generate a potential hazard. Operating Hazard Analyses (OHA) are performed to determine safety requirements for personnel, procedures and equipments used in installation, maintenance, support, testing, transportation, storage, operations, emergency escape, egress, rescue and training during all phases of intended use as specified in system requirements. Qualitative analyses are conducted to determine the technical considerations for a safe system design; quantitative analyses provide a numerical assessment of the relative safety of a system design.

System safety engineering participates in all program and design reviews in order to assess the status of compliance with the overall safety program objectives. Because system safety becomes involved in all design functions, mandatory attendance is required at meetings concerning design changes, change notices and orders, the origin of design requirement sheets, and trade studies.

Of considerable importance to personnel who handle, store and transport explosive ordnance or propellants is the hazard classification of the material to be handled. Four hazard level categories have been

established as follows:

(a) Category I - Negligible. Described by conditions producing hazards that will not result in personnel injury or system damage.

(b) Category II - Marginal. Described by conditions producing hazards that can be counteracted or controlled without injury to personnel or major system damage.

(c) Category III - Critical. Described by conditions producing hazards that will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival.

(d) Category IV - Catastrophic. Described by conditions producing hazards that will cause death or severe injury to personnel, or system loss.

In cases where system safety analyses indicate that Category III or IV hazardous conditions can exist, the item must be redesigned to eliminate the hazard; or in rare cases, a specific countermeasure or detailed procedure may be prescribed.

There are many documents applicable to system safety engineering, several of which are called out as mandatory items in contract relations. In addition to those documents that specifically describe system safety engineering requirements, there are about three hundred other specifications, regulations, standards, technical memorandums, orders and directives that may be used as authority for adhering to system safety principles.

The following useful list of primary documents involving explosive ordnance is an aerospace system engineering preferred list of publications applicable to the solution of mutual interface problems:

AFM 127-100	Explosive Safety Manual. (Gives operational commanders safety criteria for operations involving explosives.)
MIL-STD-709	Ammunition Color Coding (Establishes the color coding system to be applied to service and training ammunition including guided missiles.)
DoD 4145.26M	Contractor's Safety Manual. (Sets forth practices for all work performed in connection with DoD contracts involving ammunition, explosives, and related dangerous materials.)
DOT Regulations	Department of Transportation Regulations governing transportation of hazardous materials.
TB 700-2, NavOrdInst 8020.3, TO 11A-1-47, DSAR 8220.1	Explosive Hazards Classification Procedure. (Sets forth procedures and specifies tests for determining the reaction of ammunition, explosives and solid propellants to specified initiating influences.

MIL-STD-810B	Environmental Test Methods. (Establishes uniform environmental test methods for shock and vibration of explosive ordnance containers.)
MIL-STD-454	Standard General Requirements for Electrical Equipment. (Requirement 1 - Safety (Personnel Hazard))
MIL-STD-882	System Safety Program for Systems and Associated Subsystems and Equipment, Requirements for. (Establishes requirements for application of system safety principles to a program from start to completion.)
AFM 71-4, DSAM 4145.3, TM 38-250 NAVWEPS 15-03-500	Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft. (Provides instructions for preparing explosives and other dangerous materials for shipment by military aircraft.)
MIL-STD-129	Marking for Shipment and Storage. (Provides requirements for uniform marking of military supplies and equipment for shipping and storage.)

National Ranges

WSMR	Range Users Handbook. (Specifies requirements to be filled prior to obtaining approval for use of the range.)
AFETRM127-1	Range Safety Manual (Contains range safety requirements common to all missile launch operations supported by Air Force Eastern Test Range.)
AFWTRM 127-1	Range Safety Manual (Contains range safety requirements common to all missile launch operations supported by Air Force Western Test Range.)

Although system safety engineering accomplishes its primary purpose during the design and development phases of a program, follow-on safety activities are required to ensure that the ultimate user becomes properly indoctrinated in the unique safety concepts associated with each specialized program.

Since the subject of system safety engineering is a contractual item that appears in all aerospace requests for proposal, it involves the normal requirements for administration. The SSPP must be maintained, analyses

must be made and submitted, reports of activities must be prepared, and travel must be performed to witness flight tests.

C. System Safety Test Considerations

During development and operational testing, several types of safety are involved. Primary aerospace safety test considerations are found at the range, on the ground, in flight, and during test operations with nuclear weapons.

Range Safety. "Range safety" includes all types of safety as encountered on any missile test range; examples are industrial safety, system safety, explosive ordnance safety, flight safety, and ground safety.

Ground Safety. "Missile ground safety" attempts to provide protection from all known hazards during the time from missile preparation until missile launch, including disarming if the missile is not launched. The types of hazards that may exist are fire, blast, fragment damage, toxicity and radiation. All tasks and hazardous operations associated with missile storage, handling, preparation and checkout involving explosive ordnance, toxic fuels or high-pressure gases must be performed in accordance with policy and criteria contained in appropriate safety manuals and regulations.

Each missile firing system shall have an arming provision that will directly interrupt the power flow path between power supply and initiator. A "no-voltage" check is required prior to connecting any electric initiator

into an ordnance circuit. Continuity tests on circuits containing electric initiators will be performed only under conditions where there will be no hazard to personnel or damage to facilities if the initiator should fire. Proposed procedures will be planned to minimize exposure of electro-explosive devices to RF energy. In order to conduct the necessary studies and to develop the required safety plans, the following data should be generated:

(1) Detailed written procedures for all new or modified missile handling, preparation and checkout operations involving explosive ordnance, propellants, toxic fuels or high pressure gases.

(2) A listing of all hazardous items proposed for use.

(3) A schematic of circuits used to initiate explosive materials.

(4) A listing, with frequencies and power output, of all RF energy radiating devices required in or near the missile during periods when explosives or propellants are present or installed.

Flight Safety. A Flight Safety System (FSS) is necessary in all unmanned vehicles capable of violating the boundaries of their flight test area or that cannot reliably be predicted to impact within a pre-assigned test area. A description of the proposed system for attaining emergency thrust termination, parachute ejection, missile destruction, booster separation, and other functions that could affect flight safety must be generated. Circuit diagrams of all vehicle-borne missile flight safety units are required. Schematics and diagrams of the proposed Flight Safety System, launch preparation equipment, and FSS interfaces with other missile sub-

systems are required. Flight termination system data is required in connection with the ordnance destruct package and its associated circuitry. Each unmanned aerodynamic missile launched will be equipped with a flight termination system. Pre-launch checks performed on the FSS during the missile countdown will be monitored. A description of the expected effects of destruct action on the missile will be provided. An estimate of the additional velocity imparted by the destruct system action should be included as well as an impact dispersion study of the destruct fragments. Consideration must be given to automatic missile destruct in case of structural breakup, loss of telemetry, loss of guidance signal, and to a manual method.

Nuclear Safety. Although the release of nuclear energy is not normally accomplished without the use of explosive ordnance, the safety aspects of testing any weapon with nuclear warhead installed cannot be underestimated. Precautions must be taken to prevent the occurrence of inadvertent launch or ignition. In order to accomplish a finite safety level, it has been suggested by those knowledgeable in the nuclear effects fields that the probability of inadvertent launch of a missile with a nuclear warhead should not be greater than one in one hundred million (1×10^{-8}). Prevention of nuclear yields in an accident environment is a function of the specific warhead design. The AEC normally advises the DoD that the warhead will meet such restrictive requirements and the service department concerned will accept a certification from the AEC. Certification by the AEC notwithstanding, the DoD, in the interests of safety, insists on designs that will prevent accidental

or inadvertent arming of the warhead. If adequate means have been taken to prevent arming, the probability of detonation is less than if the same effort had been applied to prevent firing of the warhead. An unarmed warhead is less likely to produce a nuclear yield if involved in an accident or incident than an armed warhead. For this reason, such specific design features as listed below are desirable and should be considered in any system safety evaluation of a nuclear subsystem:

(1) Warhead arming devices should be of the fail-safe type.

(2) Arming signals should have a continuous source of power from arming to detonation.

(3) Arming signals should have independent sources.

(4) Arming features should not be susceptible to common environment.

(5) Separate arming and firing signals should be used to produce a nuclear yield.

(6) Special safety devices should be used to interrupt critical arming circuits.

(7) Monitoring circuits should be isolated from functional circuits.

(8) Circuit design should provide against the probability of inadvertent or unplanned arming of the warhead.

(9) Each design should prevent spurious ground currents during operations such as handling, loading, or testing.

(10) Monitoring current should be limited to a value less than that required to operate the most sensitive device included in the warhead and its components.

(11) Test points and component design will be controlled to assure that application of signals and single-point failures cannot bypass the functions of the safety device.

(12) Field functions to be performed on a warhead section will be held to a minimum.

(13) Self-destruct systems will be designed to retain their reliability under all conditions, including missile break-up.

(14) Safety features incorporated in the system will be compatible with system operational employment.

(15) Monitoring indications of safe conditions will be isolated from dud monitoring.

Potential system safety hazards uncovered during the process of nuclear munitions design reviews will be analyzed and evaluated in order to eliminate or minimize their effects on equipment, facilities, and personnel.

D. Shipping, Handling, and Storage of Explosive Ordnance

Shipping. Missiles, warheads, components, support equipment, and personnel must be shipped from one place to another continuously in order to maintain a weapon system; therefore, shipping facilities must be provided for safe and economic movement of the weapon accessories. Such facilities, be they by air, rail, water, or road vehicles, must properly be classified for performing special tasks. Shipment of explosives is governed by Department of Transportation (DOT) regulations in accordance with assigned

classification by the Bureau of Explosives.

Class A are solid explosives that (a) can be caused to deflagrate by contract with sparks or flame such as produced by a safety fuze or an electric squib, but cannot be detonated, (b) contain a liquid explosive ingredient, and which when unconfined can be detonated, or (c) contain no liquid explosive ingredient and can be detonated when unconfined.

Class B explosives are defined as those explosives that, in general, function by rapid combustion rather than by detonation and include some explosive devices such as special fireworks, flash powders, some pyrotechnic signal devices, and liquid or solid propellant explosives that include some smokeless powders.

Class C explosives are defined as certain types of manufactured articles that contain Class A or B explosives, or both, as components, but in restricted quantities, and certain types of fireworks.

These transportation classifications also involve rules and regulations governing the types of containers, types of transportation, and certain restrictions in the shipment of some types of explosives. Military regulations and specifications prescribe the types of containers that must be manufactured and used for the shipment of new types of propellants and explosives, whereas explosives that have been categorized previously may be shipped in previously qualified and standardized containers. Environments such as temperature, altitude, humidity, wind, rain, sand and dust, shock, and vibration must be evaluated, specified, listed for analysis for the program

concerned, and must comply with tests mentioned in MIL-STD-810B. The weapon system specification must call out the type of transportation to be utilized, and the selected carrier must then comply with the environmental restraints contained in the specification. System safety becomes very interested in any type of shipping in which shock or vibration can occur, because over-shocking parts of a missile or weapon system can generate potential hazards that will require some action to be taken. Analysis will indicate where the fault lies and corrective action will be accomplished. There are many other features of shipping requirements that, if not observed, can introduce a reduction in the system safety effectiveness of the weapon as well as the shipping system in use.

Handling. The term "handling" is a well accepted function during the build-up of a weapon system, and indeed the word appears in a great many specifications and standards used by the military. The manner in which handling is discussed does not imply that it is a definite and specific function as such, but that it occurs in many variations throughout any factory-to-launch sequence. For instance, a weapon or end item is "handled" innumerable times during its travel from the factory to a launch site. It is handled during assembly, during test, during transportation, during storage, and in fact during any number of dependent functions. The term is used in conjunction with system safety because of the implications of dropping, shocking, vibrating, or otherwise damaging the item during handling procedures. It is within this framework that system safety

must ensure that handling procedures, including the load limits of vehicles, cranes, trucks, wire ropes and other lifting devices are made applicable to the enforcement of safety in a weapon system. The responsibility of system safety during handling procedures is to ensure that neither personnel injury nor damage to equipment or facilities can occur during handling operations. Explosive ordnance will be handled in accordance with the general military specifications and standards set forth by the three services and by civil authorities. The Contractor's Safety Manual (DOD 4145.26M) is a publication prescribed for tri-service use. Each service has, in the past, had its own set of regulations that governed the handling of explosives. For instance, explosive sensitivity dictates the types of handling restrictions utilized and recognized in ordnance engineering. The types of explosive, as well as the amount, governs the rules for handling certain dangerous articles. The general rule for handling explosives includes the safety of personnel, equipment, and facilities.

Storage. From a system safety point of view, the primary considerations during the storage phase of any weapon or end item are based on environmental conditions and handling procedures. Storage environments are normally quite severe in the areas of ordnance items and explosives. Since aerospace weapons and missiles contain explosive ordnance devices, the entire weapon must be maintained in the environments called out in the specification. Handling of such items during the storage phase

involves the observance of safety regulations as established by the military and as enforced by the local storage authorities. Humidity and temperature constraints during storage are sometimes quite critical concerning operating limits, and continuous inspections and records must be maintained in order to assure that the limits have not been exceeded and that unsafe conditions do not e› ·t. System safety must ensure that potentially hazardous conditions do not develop during handling, shipping, or storage, or if the probability of a hazard existing is discovered, safety must provide safeguards or procedures for minimizing the hazard. The Army Safety Manual, as well as the Contractors' Safety Manual, prescribes the quantity-distance criteria for storage of explosive items, and since explosives, propellants, and other hazardous materials are stored in near proximity because some are contained within the missile, a close check must be kept on the amounts of explosives and the distance between them in order to comply with the regulations.

In accordance with the DoD Contractors' Safety Manual, explosive ordnance and propellant quantity-distance requirements are designed to render inhabitants of nearby communities, plant personnel, and adjacent equipments and property reasonably safe from injury or destruction from fires or explosions. Explosive weights are computed for use in the quantity-distance tables on the basis of bulk explosives, warhead and bomb explosive fillers, metal powders and pyrotechnics and small arms ammunition. Distances between selected quantities of the above types of ex-

plosives are determined by the calculated radius and degree of damage generated by the explosive, burning or mass-detonating effects of those quantities. Storage compatibility groupings categorize explosives from "A" through "Q" depending upon the magazine construction and location, effects of the explosive, rate of deterioration, sensitivity of initiation, type of packing, effects of a fire, and the quantity of explosives in a unit. Combinations of groupings may be used for storage if packaged as required by directives. In addition, the difference between long term or life cycle storage and temporary storage can make a corresponding difference in the treatment of the item. For instance, in long term storage there will not be as much handling, therefore the probability of damage is lower and the article is safer. On the other hand, during short term storage, the item may not remain in storage environments long enough to become stabilized, thereby becoming exposed to the possibility of a hazardous condition. The storage function, therefore, is an important phase of the factory to launch sequence of any weapon system. Explosives are classified for storage in accordance with their explosive characteristics, by quantity distance evaluations, by their sensitivities, and by their composition. Class A, B, or C explosives for transportation safety considerations have comparable designations for storage. In general, all Class A transportable explosives require Class 7 classification for storage. Transportable Class B explosives require Class 6, 5, 4, or 3 for storage. Class C transportable explosives require a corresponding Class 2 or 1 for storage.

Regulations contained in both the DoD Contractors' Safety Manual and the Army Safety Manual state that liquid and solid explosives cannot be stored together except under special circumstances, and tables are provided to determine the compatibility grouping of both liquid and solid explosive materials.

Documents. The rules and regulations for shipping, handling and storage of explosives are contained in hundreds of documents, some of which are mandatory, although some may be used as guides. Until recently, each military service issued its own documentation in the form of specifications and regulations. In order to reduce duplication of paper work and, in many cases, conflicts in directives, tri-service regulations revised by the Department of Defense are now in effect. The Department of Transportation Regulations (DOT) governing the transportation of hazardous materials, Dangerous Articles Tariff 14, is a typical example of the formal documentation that defines Classes A, B, and C explosives for transportation. This document also calls out the instructions for the manufacture of containers for dangerous items including special restrictions on how and when these items should be transported. The mandatory DoD Contractors' Safety Manual is another recent tri-service document that describes dangerous items, prescribes quantity-distance limitations, and defines explosive classifications for handling and storage. There are other specific service manuals and safety regulations for test operations at national ranges and on board

ship that amplify the DoD directives. The primary document for all System Safety Engineering effort in the aerospace industry is acknowledged to be the previously mentioned MIL-STD-882. This document is used to determine and enforce system safety requirements in the design and development of any weapon system including ordnance initiation devices and explosives. "Explosive Hazard Classification Procedures," a tri-service document with Army designation TB 700-2, describes the methods for testing new types of explosives and propellants to qualify them for classification by the Bureau of Explosives. Safety manuals for the handling and transportation of explosive ordnance remain the responsibility of each military service, primarily because of the differences in methods of handling, storing, and transporting.

E. Explosive Safety

General check list. Although a great many questions may be asked when preparing procedures for the conduct of explosive tests or for devising firing countdowns for systems containing explosives, there appear to be at least 11 typical electromechanical questions considered important enough to require answers prior to the completion of such tasks:

1. Are electro-explosive devices designed to preclude hazards from environmental electromagnetic fields?
2. Are arming and firing circuit connector pins isolated to preclude critical bent pin shorts?
3. Are critical cable connectors potted?

4. Are the system electrical connectors of a design arranged to preclude inadvertent reversing or mismating of cables and connectors?

5. Is the system isolated from primary power sources if exposed to abnormal thermal environments?

6. Are monitor circuits separated from functional circuits?

7. Has assurance been given that static discharges and spurious ground currents have been eliminated in the system design?

8. Are ordnance test equipment power sources designed to preclude initiation of the explosive item under test?

9. Are mechanical interlocks provided to minimize the effects of hazards that cannot be completely eliminated?

10. Have mechanical shock and vibration design limitations been met for explosive materials?

11. Has electro-mechanical design provided for the use of safety and warning devices?

If these questions can be answered in the affirmative, potential system safety hazards will be reduced to a minimum. Explosive safety restrictions apply not only to Class A, or detonatable ordnance items, but they apply in varying degrees to Class B and Class C ordnance as well at to many types of propellants. Operations with liquid and solid propellants are governed basically by similar explosive safety regulations, but there are qualitative differences. Regulations governing the use of liquid propellants must con-

sider hypergolic characteristics, chemical properties, freezing points and vapor pressure; they must also consider the different fuels and oxydizers used in liquid propellants such as hydrogen, hydrides and boranes, oxygen, and the halogens. Regulations involving solid propellants must consider sensitivities, chemical compatibility, processing requirements, qualification procedures and physical strength. Single-base, double-base, composite, and metallic-additive propellants with binders and inhibiters require special safety regulations because of potential higher specific impulse and greater energy. Liquid and solid explosives demand a greater degree of consideration because of more rapid release of energy as compared to propellants. Therefore, explosive safety restrictions are more confining than those governing operations involving lesser hazards.

Color Coding. The application of color markings to different types of explosives, materials, conditions and procedures has been a general ordnance practice for many years. For example, pipe lines, cylinders, valves and caps are painted for proper and rapid identification. Combination of colors, patterns, printing, and sizes have long been used to identify situations and conditions that may be dangerous to human beings and could cause damage to equipment. These color codes, combinations thereof, and the materials for which codes have been devised will be found in the appropriate DoD publications dealing with explosive ordnance. In addition to the actual colors used in the color coding regulations, there

are other considerations that must be observed. For example, a missile undergoing research, development, and test must be painted with a distinctive pattern of horizontal and vertical areas of differing widths in order to properly track and photograph a missile during flight. One of the missile fins, or some distinctive portion of the missile exterior, should be painted a different color than the rest of the missile in order to provide an active reference point for photography. If the particular missile is shipped in sections, or even as a wooden round in containers, specific data must be printed in letters and numbers of specific size in order to provide proper identification. For instance, in most cases of marking shipping containers, the specification data, warrantee, date of acceptance, date of manufacture, registration number, weight of cube, and lot number must be printed on the exterior of the container for proper identification.

F. Application of Safety Principles to Explosives

Electrical. Electrical applications for enhancing explosive safety principles normally occur in fire control circuits for explosive ordnance. Electrical interlocks, relays, isolation transformers, and switches are examples of devices which are frequently used in explosive control circuits to reduce or eliminate potential hazards. Electrical interlocks are "designed in" to equipment to ensure that key events occur when they are scheduled or that they do not occur inadvertently. Electrical circuits must be com-

patible from the point of view of power source, component size and economy in order to attain maximum performance and effectiveness. Power grounds, static grounds, and associated shielding must be properly designed in the interest of safety to equipment. Electrical restrictions must be advertised by warnings containing limits, safe distance, power levels, and personnel safety data.

Mechanical. Mechanical applications involving explosive safety concepts are exemplified by such devices as mechanical interlocks designed to prevent undesired events from occurring until a related action has occurred. Mechanical devices must demonstrate a use-effectiveness-economic factor that will adequately satisfy the system safety requirements. Explosive ordnance handling equipment, including lifting devices, must be tested periodically and must be stamped with the required and approved safety factor. Mechanical S&A devices and fuzing are examples of safety efforts to prevent explosive ordnance incidents.

Environments. When working with explosive ordnance, operators must consider the many limitations required by a local environment. Temperature restrictions, both minimum and maximum, must be strictly observed when handling, transporting, or storing explosive ordnance. Likewise, humidity and pressure limitations must be observed. Neither liquid nor solid explosives can withstand excessive shock or vibrational environments because of their inherent sensitivities. A recent phenomenon involving electrostatics has entered the explosive ordnance operational field in that

non-conductive materials such as some plastics and some rubberized materials can generate and hold high voltages. The charge itself is of minor concern; it is the electrostatic discharge, the discharge path, and the current flow that constitute the hazard. A spark discharge of any magnitude, since it is an ignition source, is of course an undesired hazard when it occurs near a propellant or explosive.

Explosive hazard prediction. Techniques have been developed that provide for estimating the probability of the occurrence of a premature or inadvertent explosive event within a system or subsystem. As stated previously, fault hazard and fault tree analyses are tools by which system safety engineering can predict the presence of a hazard and can then recommend measures to eliminate or reduce the effects of that hazard. For example, in order to determine the probability of an inadvertent activation of a Flight Safety System (FSS) destruct package, a failure mode and effects analysis (FMEA) must be conducted to determine the failure modes of major components such as detonators, safing and arming devices, command destruct receivers, electrical circuits, and mechanical design; then a fault hazard analysis (FHA) must be performed to determine the hazard classification category of selected components and combinations of components in relation to their contribution to an inadvertent action; and, finally, a fault tree analysis (FTA) will determine the probability of Class I and II potential hazards contributing to the inadvertency, thus allowing the formulation of procedures to eliminate or reduce them. Class III

and IV hazards will be eliminated by design changes or procedural directives. Briefly, the fault tree is constructed by placing the inadvertent action or undesired event at the apex of the "tree", which is the beginning of a logic diagram. The process then progresses backwards through "and" and "or" gates to (1) trace those several activities that must occur together ("and" gate) to produce a failure to cause the hazard, and (2) identify those actions of which any one of several ("or" gate) can occur to produce a failure in the tree leading to the formulation of a hazard. Next, by the application of statistical performance to the logic tree branches in terms of failure rates, and by employing Boolean algebra principles to eliminate the not-so-obvious non-contributors to the hazards, a probability of occurrence number is developed. With such a probability at hand, it is not difficult for the safety engineer to recommend what corrective action should be taken in order to declare the flight safety system and its components safe for operation.

System safety principles must be applied to all types of explosive ordnance in electrical, mechanical and environmental operational areas in order to detect, identify and eliminate or minimize the effects of potential hazards to personnel, equipment, or facilities.

G. Conclusions

The interface relationships that exist between system safety and explosive ordnance engineering functions are mutual. Explosive ordnance

can be made relatively safe for manufacture, test, and operations through the application of system safety engineering principles. These principles are employed in additional tasks such as in shipping, handling, and transportation of explosives in order to comply with the many applicable safety-related regulations and other directives. The System Safety Program Plan is the system safety engineering guide for ensuring that effective analyses are conducted to eliminate hazards, to eliminate the effects of potential hazards, and to ensure that they will result in minimum injury or damage. If explosive ordnance engineers will apply system safety engineering criteria to all facets of explosive technology, injury to personnel or damage to equipment and facilities can be eliminated or reduced to an acceptable level.

"CRITICAL MASS (HYPOTHESIS AND VERIFICATION) OF LIQUID ROCKET PROPELLANTS"

by

Dr. Erich A. Farber, Professor & Research Professor of Mechanical Engineering

Abstract

This paper introduces the new concept of "CRITICAL MASS" for liquid rocket propellants and verifies its existance.

Due to internal mechanisms of the mixing of fuel and oxidizer, self generated ignition conditions and centers are produced, which even in the absence of external ignition sources, limit the size and quantity of liquid rocket propellants which can be brought together without resulting into an explosion.

A Fluid Plug Model is presented which describes the mixing process and through electrical analogy the electrostatic phenomena in the mixture. Experimental studies presented verify the theory.

The effect of the energy, which is used in bringing the propellants together, upon the Critical Mass is discussed and presented in graphical form.

Finally the Critical Mass predictions, based upon the above hypothesis are compared with the results from actual large scale liquid propellant explosions.

PRECEDING PAGE BLANK

Introduction

When large quantities of liquid fuels and oxidizers are brought together during experiments or accidentally, the results are liquid propellant explosions.

Many different phenomena can trigger the explosion, such as flames, sparks produced by striking or breaking metal structures, hot materials or hot spots produced by slow chemical reactions of fuel and oxidizer, the breaking of crystals which are formed when one of the liquid components freezes the other and which are broken mechanically or by thermal stresses, or by static electricity which is a result of internal friction, and which may produce a spark discharge.

Many more possibilities could be cited but these additional sources do not change the basic picture.

From the above it can be seen that as soon as there is contact or mixing of the fuel and oxidizer, ignition is possible if an ignition source is available. If not, the mixing process may proceed with more and more of the fuel and oxidizer mixing until an ignition source appears, either through external or internal action.

This paper discusses the inherrent production of an ignition source due to the mixing of oxidizer and fuel, specifically for cryogenic rocket propellants.

It has been well documented over many years that when layers of liquids move across each other that electric double layers are produced resulting in electrostatic charges, and

if the liquids are good dielectrics so that the charges cannot leak off rapidly, into very high voltage differences.

If a gas bubble or other medium of lower dielectric constant is interposed between the highly charged liquid layers, electric breakdown can occur and a spark jumps which may well act as the source of ignition.

Since this electrostatic build-up is always present within the mixing regions of fuel and oxidizer of dielectric liquid rocket propellants, electric discharge is inevitable when the voltage difference has reached the necessary value for breakdown to occur across one of the bubbles, produced by the boiling of the constituent with the higher boiling point.

This study is rather general but was applied here to mixtures of LO_2/RP-1 and LO_2/LH_2, propellant combinations of main interest at this time.

It will be shown that voltage build-up increases with the quantities or masses of propellants involved and the ignition probability reaches a value of one (or becomes a certainty) when large enough masses are involved. When this occurs the quantities involved, which have actually been mixed, will be referred to as CRITICAL MASS.

Fluid Plug Model

Much work was done with bulkhead type failures since they are likely ones, one of the more gentle methods of bringing the components together, This type was selected in connection with this work since large amounts of

experimental data are available, involving cryogenics for either fuel, oxidizer or both. The bulkhead failure mode was then used to formulate the Fluid Plug Model.

When one component of a fuel-oxidizer combination falls into the other this can be likened to a plug of fluid falling into the other. Fig. 1.

When the fluid plug of one component enters the other component heat transfer at the contact surface area, which can be calculated, results in large amounts of vapor generated. The amount of heat transfer constantly changes since the contact area changes, and the resulting amount of vapor generated as a result varies constantly making the fluid plug bobb up and down.

The variable amount of vapor generated with time and the varying fraction of this vapor which is entrained at any one time in the fluid plug, provides the force and mass of the plug to describe its motion. The resulting motion is an oscillation with varying and generally decreasing amplitude due to the constantly varying driving force on, and the constantly varying mass of the fluid plug.

The fluid plug motion can be expressed mathematically as

$$\Sigma F_y = \frac{d}{d\tau}\left(m \frac{dy}{d\tau}\right) \qquad (1)$$

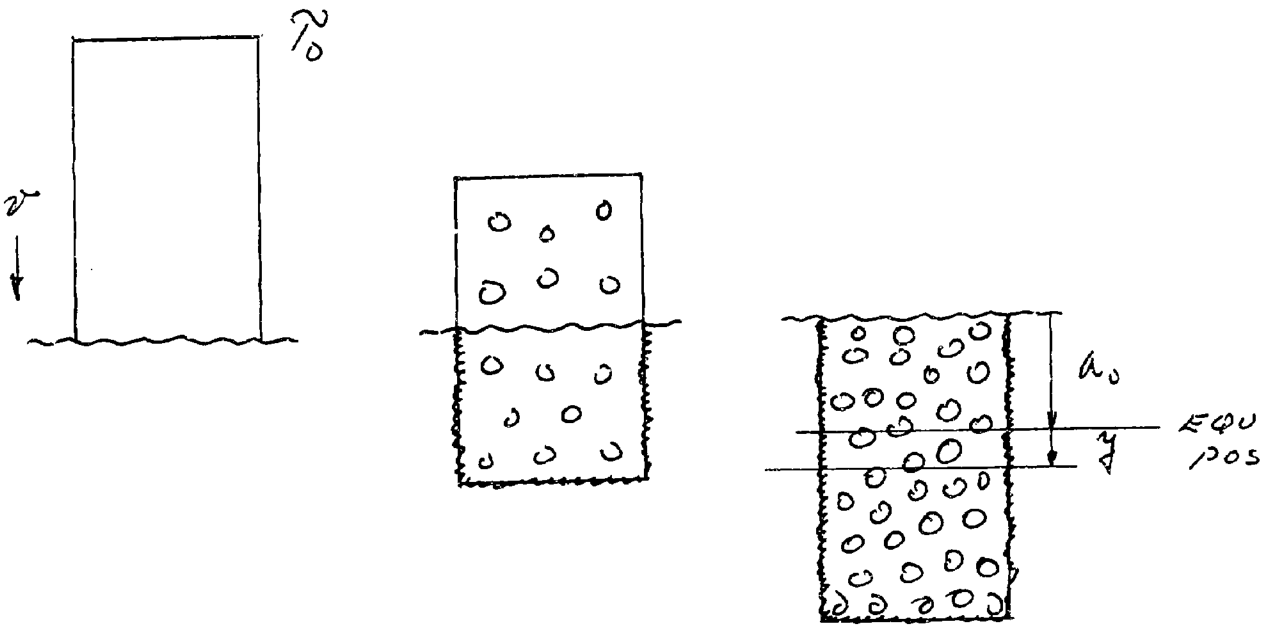


Fig. 1 The Fluid Plug Model

where
$$m = \frac{\rho_L V_{Lp}}{g} + \frac{\rho_g V_{gp}}{g}$$

$$= \frac{V_{Lp}\,\rho_L}{g} + f\,\frac{V_g\,\rho_g}{g}$$

$$\simeq \frac{\rho_L}{g}\left(V_p - f V_g\right) \qquad (2)$$

and ΣF are the forces acting on the fluid plug, m is the constantly varying mass of the fluid plug, y the displacement from the instantaneous equilibrium position, and τ the time.

The density of the liquid in the plug is ρ_L, the volume of the liquid in the fluid plug is V_{Lp}, the density of the vapor in the fluid plug is ρ_g, and the volume of the vapor in the fluid plug is V_{gp}, with g being the gravitational constant. V_g Is the total volume of vapor generated and f is the fraction of it which is entrained in the fluid plug at time τ.

The volume of V_p of the fluid plug can be, if a cylindrical configuration is taken, expressed in terms of the fluid plug radius R_p, and fluid plug height H.

$$V_p = \pi R_p^2 H \qquad (3)$$

Considering the heat transfer at the surface of the fluid plug

$$q = h \bar{A} \Delta T \Delta \tau$$

$$= V_g \rho_g h_{fg} \qquad (4)$$

with q the heat transfer in Btu, h the heat transfer film coefficient, $\bar{A}$ the average are of heat transfer during the interval $\Delta \tau$, ΔT the temperature difference, and h_{fg} the latent heat of vaporization.

From equation (4) the amount of vapor generated can be calculated.

$$V_g = \frac{h \bar{A} \Delta T \Delta \tau}{\rho_g h_{fg}} \qquad (5)$$

Using the above equations and relationships the equation of motion for the fluid plug can be written.

$$\Sigma F = -\rho_B \pi r_p^2 y$$

$$\approx \frac{d}{d\tau}\left[\frac{\rho_L}{g}\left(\pi r_p^2 H - y\,\frac{k\bar{A}\,\Delta T\,\Delta\tau}{\rho_g\, h_{fg}}\right)\frac{dy}{d\tau}\right] \tag{6}$$

$$\bar{A} = \frac{\int_0^{\tau}\left[\pi r_p^2 + 2\pi r_p (a_0 + y)\right] d\tau}{\int_0^{\tau} d\tau}$$

$$= \frac{\pi r_p^2 \tau + \int_0^{\tau} 2\pi r_p (a_0 + y)\, d\tau}{\int_0^{\tau} d\tau} \tag{7}$$

$$y = \phi(\tau) \tag{8}$$

In the above equations ρ_B is the density of the liquid surrounding the fluid plug, a_0 the instantaneous equilibrium position or center of oscillations during $d\tau$, ϕ a function which has to satisfy the motion as dictated by the heat transfer and resulting vapor generation.

The above equation is very complex and for this reason simplifications are made by assuming that H is constant for all the cyclic increments, and that ρ_p is made to vary

to compensate for this assumption.

Solutions giving excellent agreement with experimental work can be made by further simplifying the conservation of momentum equation to

$$-\rho_B \pi R_p^2 y = \frac{\rho_L}{g}(V_p - f V_g)\frac{d^2 y}{d\tau^2} \qquad (9)$$

or

$$\frac{d^2 y}{d\tau^2} + \frac{g \rho_B \pi R_p^2}{\rho_L (V_p - f V_g)} y = 0 \qquad (10)$$

which has solutions of the form

$$y = C' \cos \omega \tau + C'' \sin \omega \tau \qquad (11)$$

with

$$\omega = \left[\frac{g \rho_B \pi R_p^2}{\rho_L (V_p - f V_g)}\right]^{\frac{1}{2}} \qquad (12)$$

C' and C'' being arbitrary constants, and ω the instantaneous frequency of oscillations of the fluid plug.

The above equations can describe the actual motion of the fluid plug by successive application to fractions of cycles or successive time intervals. This can be indicated by

$$\left.\begin{array}{ll}
\dfrac{d^2 y_1}{d\tau_1^2} + \omega_1 y_1 = 0 & \qquad \tau_0 \le \tau \le \tau_1 \\[2ex]
\dfrac{d^2 y_2}{d\tau_2^2} + \omega_2 y_2 = 0 & \qquad \tau_1 \le \tau \le \tau_2 \\[2ex]
- - - - - - & \\[2ex]
\dfrac{d^2 y_n}{d\tau_n^2} + \omega_n y_n = 0 & \qquad \tau_{n-1} \le \tau \le \tau_n
\end{array}\right\} \tag{13}$$

with the solutions of

$$\left.\begin{array}{l}
y_1 = C_1' \cos \omega_1 \tau + C_1'' \sin \omega_1 \tau \\
y_2 = C_2' \cos \omega_2 \tau + C_2'' \sin \omega_2 \tau \\
- - - - - - - - - - \\
y_n = C_n' \cos \omega \tau + C_n'' \sin \omega_n \tau
\end{array}\right\} \tag{14}$$

and the boundary and initial conditions for each cycle increment. The final conditions of one cycle increment form the initial conditions for the next.

$$\tau = \tau_i, \quad y = -\bar{a}_i, \quad \frac{dy}{d\tau} = v_i,$$

$$\bar{a}_i = \frac{\bar{e}P_i}{eB_i} H_i \qquad (15)$$

where the subscript i refers to the instantaneous values for the cycle increment under analysis.

From the above the total displacement (submergence) Y_i of the plug is

$$Y_i = a_i + y_i$$

$$= \frac{\bar{e}P_i}{eB_i} H_i + C'' \sin \omega_i \tau \qquad (16)$$

And the volume mixed at time $\tilde{\tau}_i$ is

$$V_i = \pi r_{p_i}^2 \, Y_i \qquad (17)$$

And the contact area at time $\tilde{\tau}_i$ is

$$A_i = (\pi r_{p_i}^2 + 2\pi r_{p_i} \cdot Y_i)\, F_T \qquad (18)$$

where F_T is a turbulence factor which may be added if the contact surface is very turbulent or stirred up.

In using the Fluid Plug Model the equations can best be solved by trial and error making the necessary assumptions and then varying them until the loop which has to satisfy the physical phenomena closes. The motion of the fluid plug produced by the density changes in the fluid plug must agree with the heat transfer producing these density changes which in turn is a function of the fluid plug motion.

The detailed steps involved in the method are

a. The determination of r_{p_o}, H, v_o from the physical configuration and failure mode.

b. The selection of $\Delta\tau$ or fraction of cycle to be analyzed.

c. The calculation of V_{g_i}'

$LO_2/RP = 7776$ Btu/hr ft^2 F

$LO_2/LH_2 = 1140$ "

d. The selection of f (or calculation based upon bubble rise velocities.

e. The calculation of ω_i and α_i.

f. The use of the initial and boundary conditions to calculate the amplitude of instantaneous oscillation for the $\Delta\tau$ under consideration.

g. Calculation of the penetration.

h. The determination of the volume mixed V_{MIX} during thé interval under analysis.

This procedure is then repeated as often as needed or desired to obtain the mixing function V_{MIX} versus τ.

The analysis described above, using the Fluid Plug Model for approximately half cycle increments is presented in Fig. 2.

Also plotted on this graph is the experimental result of the mixing function for LN_2/RP-1. More discussion on the experimental work will be found in a later section.

Electrical Analogy

Since, as has been discussed in literature for years, motion of fluid layers, will through the relative motion and friction, produce charged regions and set up potential

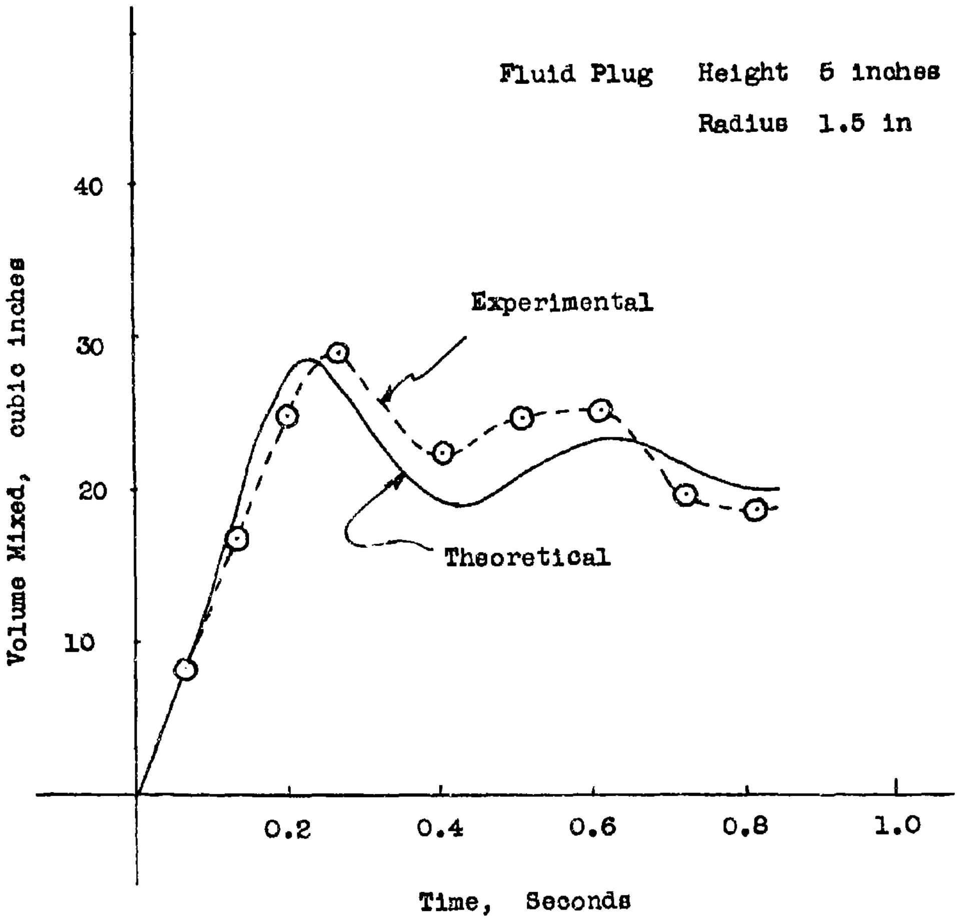


Fig. 2 Fluid Plug Mixing Function

differences within the fluid if these charges are prevented from leaking off too rapidly.

Since the motion of the fluid plug is described by the Fluid Plug Model developed, this motion should make it possible to describe also the electrostatic charge and voltage generation. Substitution in the equations of motion of the equivalent corresponding electrical quantities for the mechanical ones will provide a relationship between the charges generated and the motion of the fluid plug, the mixing and the heat transfer.

The frequency of the motion in the basic equations remains the same.

While the physical motion is, however, of oscillatory nature the charge generation and build-up is accumulative, or in other words independent of the direction of the motion of the fluid layers.

The expression becomes

$$\frac{d^2 \varphi_c'}{d\tau^2} + \omega_c'^2 \varphi_c' = 0 \qquad (19)$$

when the same basic assumption as made for simplification purposes as before. The general solution is again of the form

$$\varphi_c' = D_c' \cos \omega_c' \tau + E_c' \sin \omega_c' \tau \qquad (20)$$

Q_i' is the instantaneous charge generated and D_i and E_i' are arbitrary constants. ω_i' is the one determined from the physical motion of the fluid plug.

These equations allow the calculation of the charge generated during each time interval or cyclic increment, with the constants determined from either experiment or physical and electrical properties of the fluids.

To obtain the accumulated charge, which is the quantity which eventually provides the ignition source through generation of the required potential is obtained from

$$Q = \sum_i |Q_i| \tag{21}$$

where Q is the total accumulated charge calculated from the summation of the absolute values of the charges generated for the cyclic increments.

Fig. 3 presents two curves of charge generation calculated in this manner from the fluid plug model. The lower curve is calculated for a fluid plug 3 inches in diameter and 5 inches high. It corresponds to the use of 140 in^3 of LN_2 in a 50% bulkhead failure arrangement (d/D=0.5).

The upper curve represents twice the quantity or a fluid plug twice as high. It is shown that the doubling of the mass produced essentially twice the charge. Experiments over two order of magnitudes demonstrated a linear

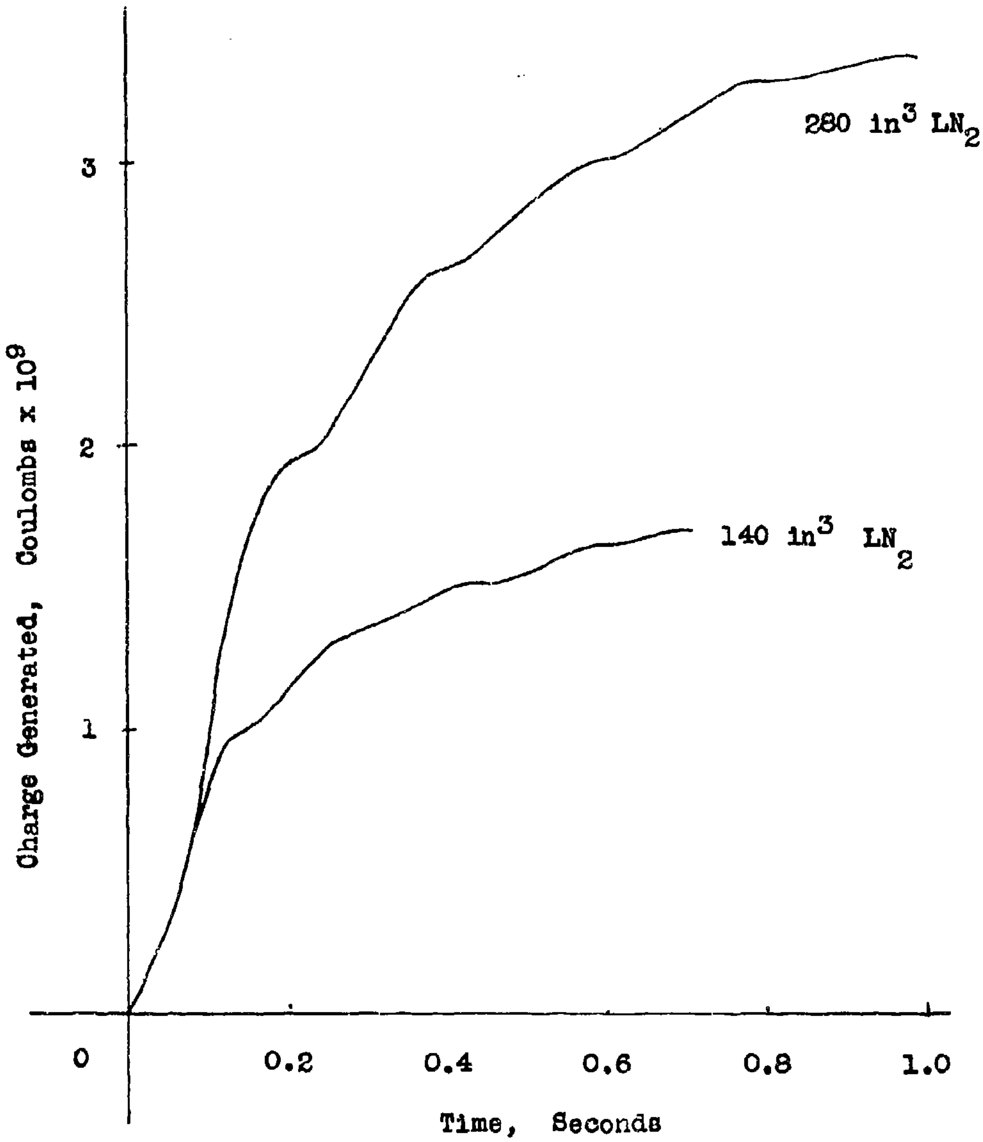


Fig. 3 Theoretical Charge Generation, Fluid Plug Model

relationship.

In all the experiments carried out with both organic (hydrocarbon) fuels and LN_2 as well as inorganic liquids such as distilled water and LN_2, it did not seem to make any difference whether the mixing to produce the electrostatic charges was carried out in steps or the total mass was brought together all at once. This is only true if the leakage was negligible since the step by step mixing took much more time to produce the same charges.

Since the fluid layers act as plates of a capacitor, or the electrode screens inbedded in the fluid layers the relationship between electrostatic charge, capacitance C, and voltage V can be used.

$$Q = C V \tag{22}$$

With the Q calculated from the equations of motion and the electrical equivalencies, C from the physical configuration, V can be obtained from equation (22).

The voltage build-up obtained in this manner is presented in Fig. 4. It is presented here as a function of mass which is the form in which it will be used later for determining the Critical Mass.

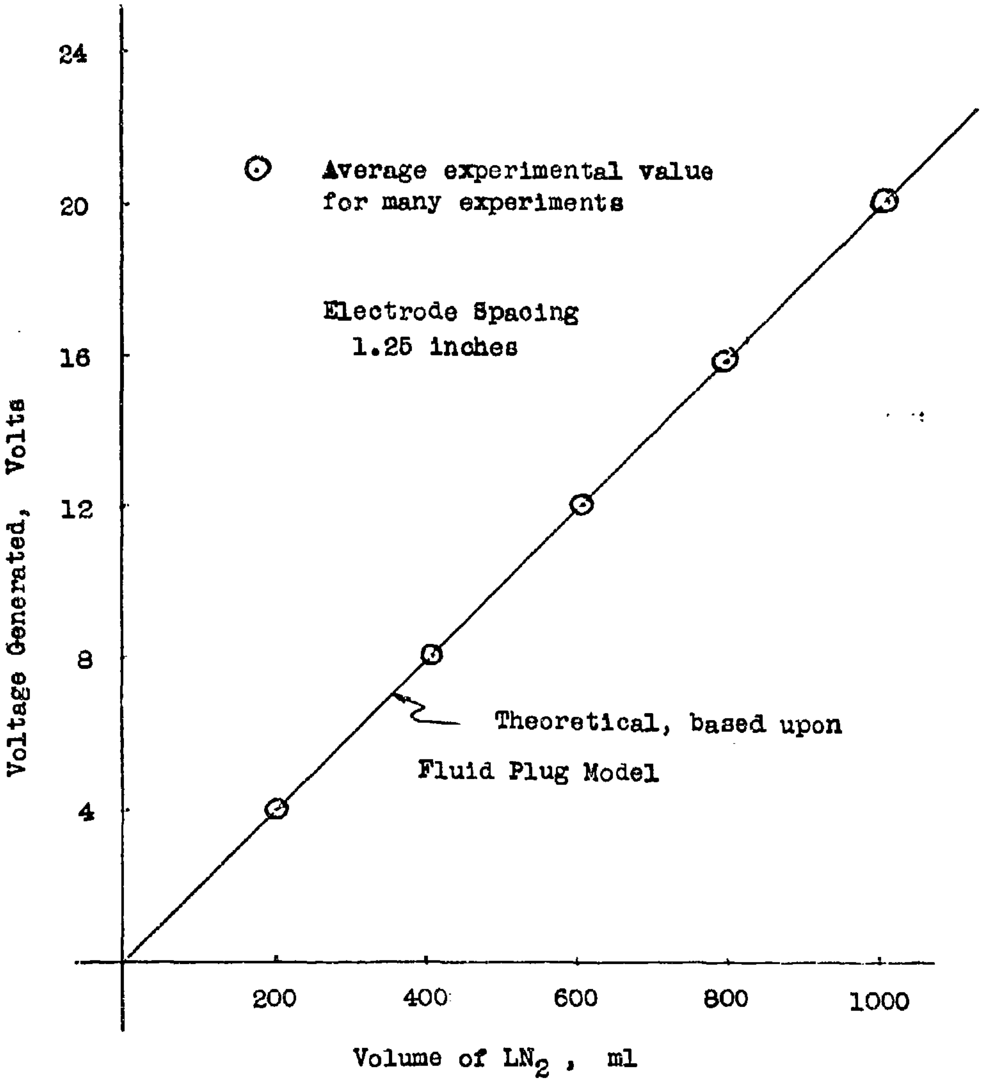


Fig. 4 Voltage Generated as a Function of LN_2 Quantity

Experimental Verification

To verify the results obtained by use of the Fluid Plug Model a simple experiment was set up. Fig. 5 schematically describes it. A glass cylinder was used and filled to a desired level let us say with RP-1. Above the RP-1 was a partition with a hole in the center which could be opened by sliding out two plastic sheets. The hole diameter was 1/2 that of the glass cylinder. The space above the partition was filled with the desired quantity of LN_2 and when the hole was quickly opened the LN_2 fell down into the RP-1 through the hole, simulating a fluid plug.

In the RP-1 space were mounted two screen electrodes, one just above the RP-1 liquid surface and the other in this case 1.25 inches below the upper one. Leads from the two screen electrodes were led to an Electrometer and its output to a Brush strip chart recorder.

In this manner the charge and voltage build-up as a function of time could be determined for different combination of liquids and for different quantities.

The actual traces obtained look very much like the theoretical traces of Fig. 3. Again it does not seem to make any difference whether the whole quantity is used all at once or in steps, providing in the latter case leakage is prevented.

The elctrode screens actually give many possible pick-up positions and the voltage or charge readings can be obtained

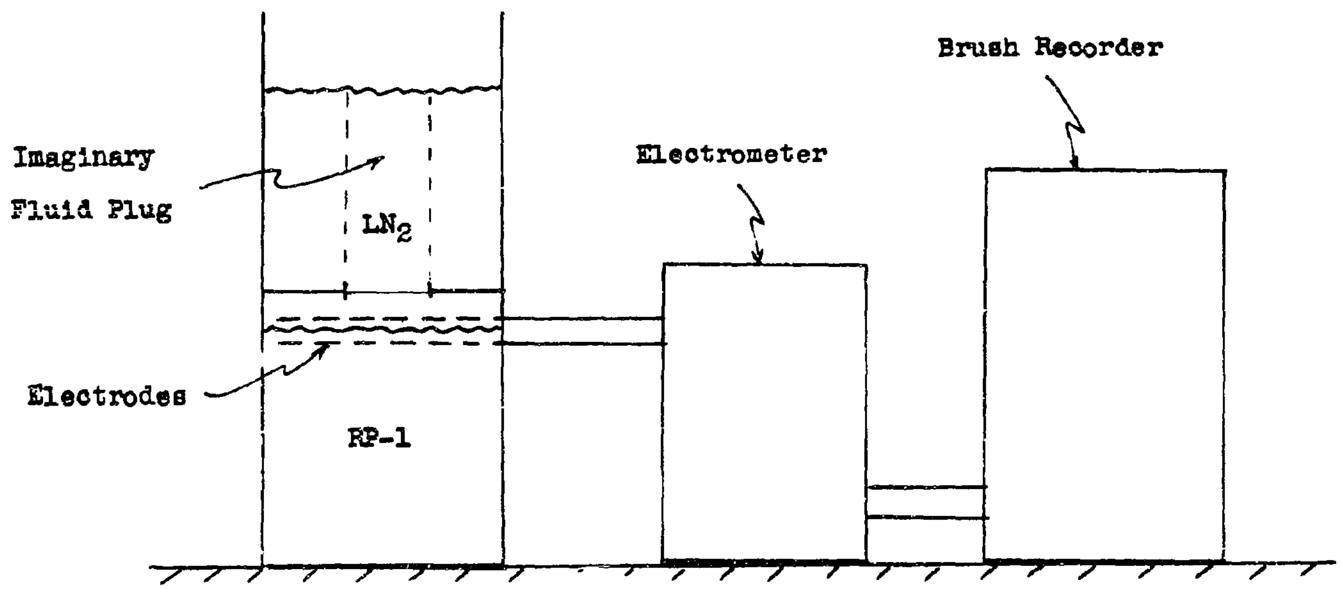


Fig. 5 Experimental Set-Up For Electrostatic Charge and Voltage Generation Measurements

every time. With single point electrodes sometime a charge or voltage is measured and sometimes not. The reason was that the instrumentation sensor has to be located in the fluid at the point or in the regions where the charges and voltages are generated.

Sometimes voltages of opposite polarity are recorded since with the turbulence in the mixing region the charged layers can come in contact with either electrode, and each one can become positive or negative with respect to the other. The actual amounts of voltage generated and recorded did in general not vary too much but on occasion a large jump is observed.

The average voltage generated with electrode spacing optimum, based upon many observations, was for 200 ml of LN_2 4 volts. This voltage was built up through the use of large quatities or small quantities in succession to several hundred volts.during these experiments. Sometimes but not very often a single jump of several hundred volts was observed with as little as 200 ml of LN_2.

When the large quatities were allowed to come together it seemed that the mixing takes place in very rapidly repeated jumps so that the same voltage was reached as if the same quantities were mixed in discrete steps. Since the mixing occurs in such small steps over and over again the average value takes on much more meaning especially when applied to large quantities.

The manner of mixing did not seem too critical since just pouring one component into the other produced essentially the same results. The reason for this seems that the boiling action which provides considerable violence to the mixing process is the over-riding phenomenon. If however considerably more mixing energy is used, such as the pouring from a height of 10 feet, the mixing and the charge generation and voltage generation occur much more rapidly.

It seemed, however, that the mixing occured relatively more rapidly than the charge and voltage build-up when compared with the more gentle method of bringing the components together. Fig. 6 shows an actual trace of voltage versus time for 200 ml incremental LN_2 additions.

Due to the small quantity of RP-1 and the rapid additipn of LN_2 the temperature difference between the components decreased during this test showing the effect of less vapor generation in the later additions, resulting in deeper penetration of the fluid plug and therefore more voltage generation.

From the high speed film analysis which was used in the analysis (developed and reported upon earlier by the writer, and which agreed well with the other methods developed by the writer and his group such as the "Wax Cast Analysis" and the "Thermocouple Grid Analysis") also indicated that the bulk of the bubbles was very uniform in size and very close to 1/4 inch in diameter. There were larger and smaller ones but they were very few in number.

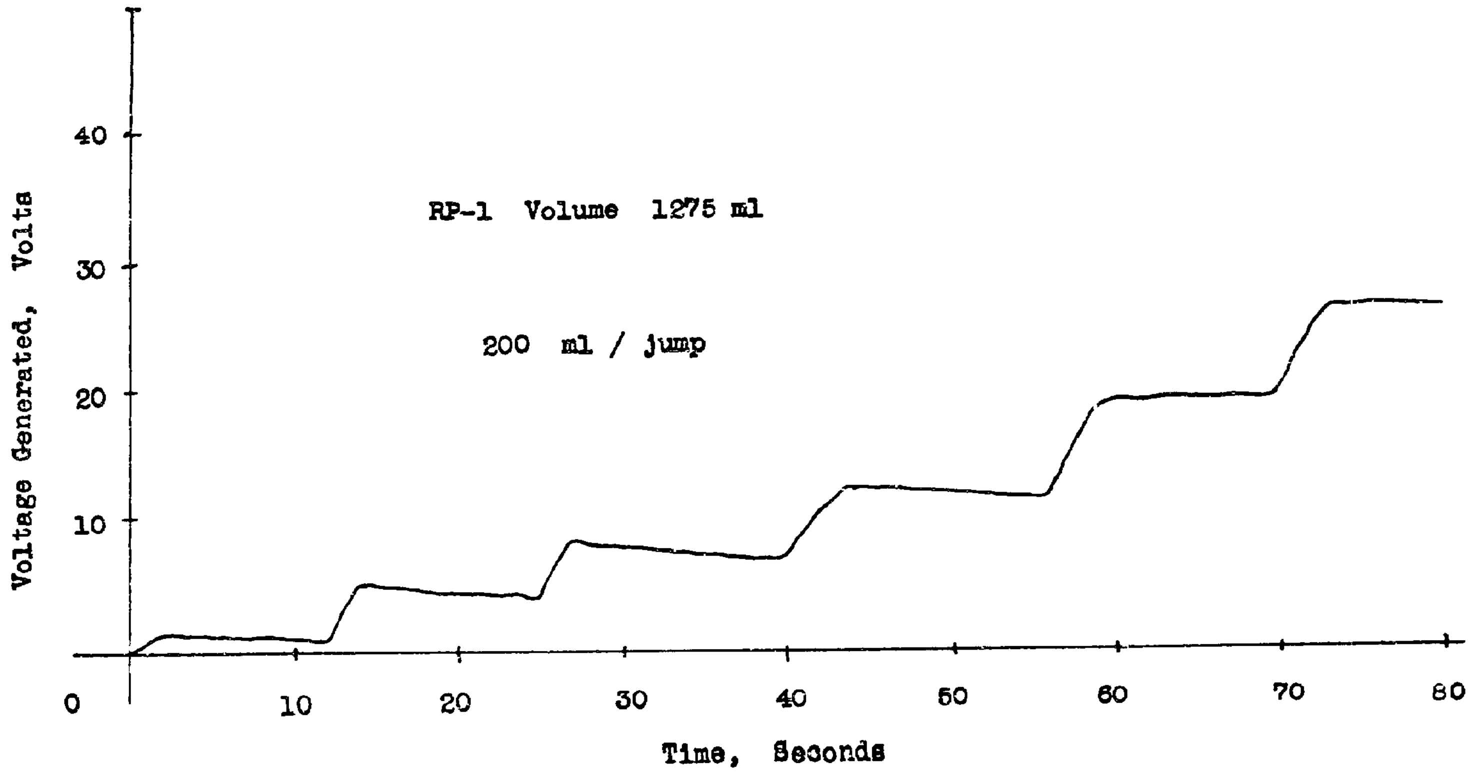


Fig. 6 Typical Voltage-Time Trace for Successive Mixing of LN_2 and RP - 1 Using Small Quantities of LN_2

Critical Mass

The hypothesis proposed here, and believed to have been verified, is that in the absence of any external ignition sources a mixture of fuel and oxidizer will internally, through the nature of the mixing process produce electrostatic potentials which will reach values at which break-down, through sparking, occurs, supplying ignition sources . f the explosive mixture.

As a consequence of the above it is impossible to mix unlimited amounts of cryogenic rocket propellants since the voltage build-up becomes larger as the quantity mixed becomes larger and finally with a certain limiting quantity mixed, ignition becomes a certainty since break-down will occur. This quantity is referred to by the writer as CRITICAL MASS.

Basically what this means is that an explosion can occur at any time with any quantity of explosive mixture, but the probability of it to occur increases and finally becomes a certainty at a particular quantity and it is impossible to mix quantities larger than this limiting value or Critical Mass without an explosion to occur. Ignition is a certainty to occur as soon as the Critical Mass is reached.

According to the literature it takes 0.02 millijoule to ignite hydrogen and under unusual conditions it has been ignited by 1300 volts. Usually it takes higher potential differences and voltages of 14,000 and 20,000 volts are quoted. Some authorities, according to these sources,

consider it necessary to have an electric field strength of 76,000 volts per inch before sparking can occur.

Using the last number it would require about 19,000 volts for discharge across a 1/4 inch bubble, the most prevalent size in these experiments.

Further using the knowledge that 4 volts are produced at an average, for each 200 ml of LN_2 and recognizing that the physical - electrical properties needed here of LN_2, LH_2 and LO_2 are similar, it can be estimated that for a bulkhead type failure the Critical Mass, or mass which when mixed will produce this voltage, is about 2300 lb for LO_2/LH_2 and approximately 2800 lb for LO_2/RP-1.

Trusting that the above results are correct and applicable, one can estimate the maximum expected explosive yields for such failures, obtaining about 3 percent for the S-IVB PYRO experiment and about 11 percent for the 25,000 lb LO_2/RP-1 bulkhead type explosion experiments, yield values which are in excellent agreement with the reported experimental values[4,6,7].

Variation of Critical Mass with Mixing Energy (Rate).

When LO_2 and RP-1 or LO_2 and LH_2 are brought together the difference in temperature produces rather violent heat transfer. This heat transfer produces large amounts of vapor which through its violent displacement of liquid produces rather violent mixing of the fuel and the oxidizer.

With these propellant combinations under those conditions the energy released in this manner is the minimum which will contribute to the mixing process and a certain portion of this energy will produce the agitation. More gentle mixing is not possible and mixing energies smaller can only be produced when the propellant components are brought to temperatures less different from each other.

If the mode of failure is changed so that the propellants are driven together with greater energies the mixing will take place faster. The charge and voltage generation will also occur faster but does not relatively increase as much as the mixing rate.

From these considerations it can be seen that if propellants can be mixed very gently, say drop by drop, infinite quantities could be mixed, which however would take infinite time, without producing ignition. On the other hand if the propellants could be brought together with infinite energy, they could be completely mixed in zero time, again allowing the mixing of infinite quantities before ignition can occur.

This analysis then indicates that the Critical Mass when plotted against the Mixing Energy, which is supplied by both the mode of failure and the boiling process, approaches infinity both as the mixing energy approaches zero and also as it approaches infinity. Thus the plot of Critical Mass versus Mixing Energy is a distorted U curve

and all the real values which can be encountered will fall below this curve.

From mathematical analysis the Critical Mass function can be devided into two characteristic branches, the one to the left of the minimum and the one to the right, the minimum point representing the value of Critical Mass which is the maximum value which could be produced with the boiling energy of the bulkhead type failure. Since this value is easily calculated for any quantity of propellants all other cases are normalized with respect to this energy value.

From experiments with non cryogenic mixtures it is seen that the time it takes for the voltages to be reached which could produce ignition decreases with an increase in the mixing energy, approaching infinity when the mixing energy approaches zero. The relationship below closely describes this behavior

$$\tau^{*} \mathcal{E} = C_3 \qquad (23)$$

where τ^{*} is the Critical Time, or time it takes to build up the voltage necessary for ignition, and $\mathcal{E}$ is the Mixing Energy, C_3 an arbitrary constant.

From the Fluid Plug Model the mass mixed at any one time can be expressed as

$$M = C_4 \sin \omega \tau$$

$$= C_4 \omega \tau - \frac{C_4 \omega^3 \tau^3}{3!} + \frac{C_4 \omega^5 \tau^5}{5!} -$$

$$\simeq C_4 \omega \tau \qquad (24)$$

and therefore

$$M^* = C_4 \omega \tau^* \qquad \text{and from (23)} \qquad \tau^* = \frac{C_3}{E}$$

$$= \frac{C_4 \omega C_3}{E}$$

$$= \frac{C_1}{E} \qquad (25)$$

This equation is seen to give the largest values for Critical Mass at low values of Mixing Energy. Since with cryogenic propellants under normal conditions the Boiling Energy is the minimum which produces the mixing, equation (25) is not the most significant contribution.

Again from the Fluid Plug Model and laboratory experiments with cryogenic fluids it could be seen that twice the energy supplied for the mixing process produced essentially twice the mass mixed for the same time interval, three times the energy produced three times the mass mixed, etc.

This can be stated as

$$M = C_5 \, E \, \tau \qquad (26)$$

From previous work at the University of Florida with LN_2/RP-1 and the mixing studies carried out by PYRO with LN_2/LH_2 it was found that

$$M = C_6 \, \tau^2 \qquad (27)$$

Setting equations (26) and (27) equal the relationship between τ and E is obtained.

$$C_5 \, E \, \cancel{\tau} = C_6 \, \tau^{\cancel{2}}$$

$$\tau = \frac{C_5}{C_6} E \qquad (28)$$

Substituting this last obtained relationship into equation (26) gives the significant M and $\mathcal{E}$ functional relationship for Mixing Enegies larger than the Boiling Energy.

$$M = C_5 \mathcal{E} \frac{C_5}{C_6} \mathcal{E}$$

$$= C_2 \mathcal{E}^2 \qquad (29)$$

The two relationships developed (25) and (29) can now be combined for a general equation relating Critical Mass and Mixing Energy.

$$M^* = \frac{C_1}{\mathcal{E}} + C_2 \mathcal{E}^2 \qquad (30)$$

For the analysis here the Critical Mass - Mixing Energy relationship was normalized with respect to the Boiling Energy.

$$M^{*} = \frac{C_1'}{\left(\frac{E}{E_{13}}\right)} + C_2' \left(\frac{E}{E_{13}}\right)^2 \qquad (31)$$

Evaluating the constants C_1' and C_2' from the Critical Mass determination based upon the charge and voltage generation the Critical Mass Function takes on the following form

$$M^{*} = \frac{1870}{\left(\frac{E}{E_{13}}\right)} + 940 \left(\frac{E}{E_{13}}\right)^2 \qquad (32)$$

and can be plotted. FIG. 7.

Fig. 7 presents a plot of Explosion Mass (the amount of mass in any particular case which actually takes part in producing the explosion) versus the Mixing Energy Ratio (Actual total Energy producing the mixing over the boiling energy). On a plot of this sort all explosions of liquid propellants can be recorded for which enough information is available, such as yield values, and in addition the upper bound of these values can be plotted as the Critical Mass Curve.

All actual masses taking part in an explosion of

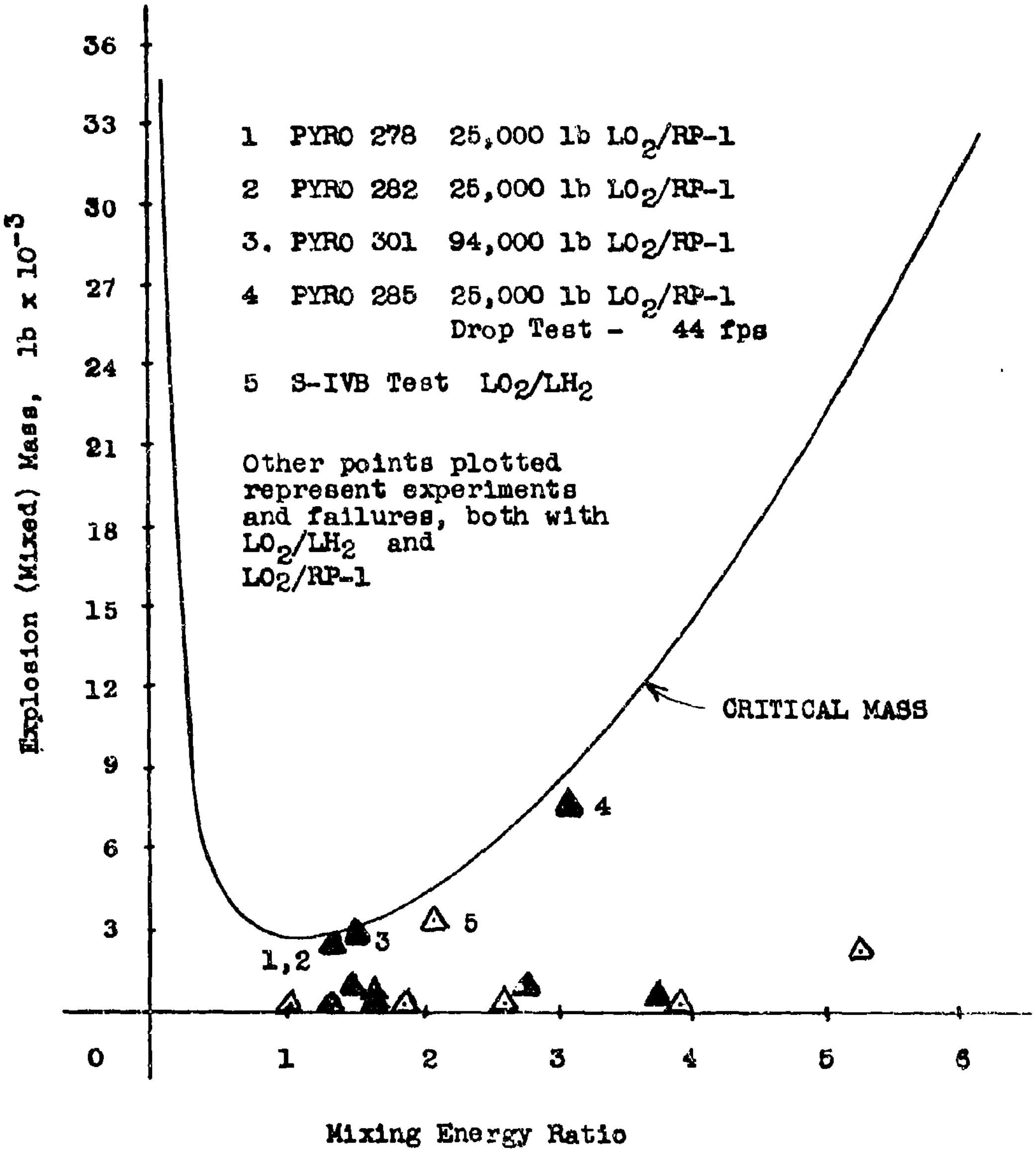


Fig. 7 Explosion Mass - Mixing Energy Relationship

liquid rocket propellants must fall below this curve.

It is seen from Fig. 7 that all known values of explosions for liquid rocket propellants for which data is available fall, when plotted in this manner, below the Critical Mass curve and only a few values approach the curve.

Many actual cases have been analyzed but only a sample of them are plotted here. For these cases the boiling energy for a bulkhead failure with equal quantity of propellants was calculated for reference and then the actual boiling, potential, and kinetic energies available for the mixing process were considered.

Closure

It is believed that this new concept of Critical Mass for liquid propellants is very useful, indicating that there are self-limiting phenomena in the mixing and explosion processes of liquid rocket propellants and that there exists an upper limit to the size of explosion which can be realized.

For total quantities of propellants less than the Critical Mass explosive yields of 100 % are possible, although the absolute size of the explosion is smaller than that produced by the Critical Mass. Furthermore maximum explosive yield values for liquid propellant explosions depend upon the mode of failure which in part at least provides the energy available to bring the propellants together.

With large quantities of propellants it is physically impossible to get all the propellants involved in an

explosion since ignition occurs at the latest as soon as the Critical Mass is reached in the mixing process, while the remainder of the propellants takes part only in rapid burning and the formation of the fireball.

The hypothesis of this self-limiting process and that electrostatic charge and voltage generation provide this physical limitation has been shown in the laboratory and has further been verified by checks against the explosive yields of large propellant quantities which were produced both by tests and missile failures.

The mathematical Fluid Plug Model presented here demonstrates how the Critical Mass can be predicted from theoretical analyses for a desired mode of failure.

The results and predictions based upon the Critical Mass Hypothesis agree excellently with actual experiments and actual failures and also with results obtained by the Mathematical Model and the Seven Chart Approach, developed and reported upon earlier by the writer and his group.

Acknowledgements

It is with deep appreciation that the writer thanks the National Aeronautics and Space Administration under whose sponsorship this work was carried out, Mr. J.H. Deese the NASA Technical Representative and Dr. C.F. Bonzon and Mr. J. Triandafyllis, who have helped both with the experimentation and analysis.

Bibliography

1. Farber, E.A., "A Mathematical Model for Defining Explosive Yield and Mixing Probabilities of Liquid Propellants," Proceedings of the Third Space Congress, March, 1966

2. Farber, E.A. and Deese, J.H., "A Systematic Approach of the Analytical Analysis and Prediction of the Yield from Liquid Propellant Explosions," Proceedings of the Third Space Congress, March, 1966.

3. "Blast and Fireball Comparison of Cryogenic and Hypergolic Propellants," Aerojet General Corp., Contract No. NAS 9-2055, Final Report, June, 1964.

4. Farber, E.A., Klement, F.W., and Bonzon, C.F., "Prediction of Explosive Yield and Other Characteristics of Liquid Propellant Rocket Explosions," University of Florida, Contract No. Nas 10-1255, Final Report, October, 1968.

5. Arthur D. Little, Inc., "Summary Report on a Study of the Blast Effect of a Saturn Vehicle," February, 1962.

6. "Liquid Propellant Explosive Hazards", Project PYRO, AF RPL, Final Report, December 1968

7. Farber, E.A., "Thermocouple Grid Analysis of Two 25,000 lb LO_2/RP Liquid Propellant Explosion Experiments," Florida Engineering and Industrial Experiment Station, Vol. XXI, No. 2, Technical Paper No. 396, November, 1967.

8. Klinkenberg, A., and Van der Minne, J.L., Electrostatics in the Petroleum Industry, Elsevier Publishing Co., 1958.

9. Helmholtz, H., "Studien ueber Electrische Grenzschichten," Annalen der Physik und Chemie, Vol. 243, No. 7, pp. 337-382 (July, 1879).

10. Cooper, W.F., "The Electrification of Fluids in Motion," Static Electrification, a Symposium held by the Institute of Physics in London on March 25, 26, and 27, 1953, British Journal of Applied Physics, Vol. 4, Supplement No. 2, pp. S 11-15 (1953).

11. Elton, G.A.H. and Peace, J.B.J., "Sedimentation Potentials. Part I. The Measurement of Sedimentation Potentials in Some Aqueous and Non-Aqueous Media," Journal of the Chemical Society (London), Vol 53, No. 1, pp. 22-26 (January, 1956).

12. Booth, F., "Sedimentation Potential and Velocity of Solid Spherical Particles," The Journal of Chemical Physics, Vol. 22, No. 12, pp. 1956-1968 (December, 1954)

13. Henry, D.C., "The C taphoresis of Suspended Particles. Part I. The Equation of Cataphoresis," Proceedings of the Royal Society of London, Series A, Vol. 133, No. 821, pp. 106-129 (September, 1931).

14. Summer, C.G. and Henry, D.C.., "Cataphoresis. Part II. A New Experimental Method and a Confirmation of Smoluchouski's Equation," Proceedings of the Royal Society of London, Series A., Vol. 133, No. 821, pp. 130-140 (September, 1931).

15. Overbeck, J.T.G., "Electrokinetic Phenomena," Colloid Science, Vol I. H.R. Kruyt (ed.). Elsevier Publishing Company, Amsterdam, Chap. V, pp. 194-244, 1952.

16. Rutgers, A.J., De Smet, M. and De Moyer, G. "Influence of Turbulence on Electrokinetic Phenomena; Experimental Determination of the Thickness of the Diffuse Part of the Double Layer," Transactions of the Faraday Society, Vol 53, Part 3, No. 411, pp. 393-396 (March 1957).

17. Rutgers, A.J., De Smet, M. and De Moyer, G. "Influence of Turbulence on Electrokinetic Phenomena; Experimental Determination of the Thickness of the Diffuse Part of the Double Layer," Experientia, Vol. 12, No. 1o, p. 371 (October, 1956).

18. Farber, E.A., and San Martin R.L., "Mixing Phenomena of Liquid Propellants Leading to a Yield-Time Function Relationship," Technical Paper No. 386, Florida Engineering and Industrial Experiment Station, Vol. XXI, No. 8, August, 1967.

19. Bocquet, P.E., Sliepcevich, C.M., and Bohr, D.F., "Effect of Turbulence on the Streaming Potential," Industrial and Engineering Chemistry, Vol. 48, No. 2, pp. 197-200 (February, 1956).

20. Arthur D. Little, Inc., "Electrostatic Hazards Associated with the Transfer and Storage of Liquid Hydrogen," Final Report, Contract No. AF 18(600)-1687, May, 1961.

21. Farber, E.A., and Gilbert, J.S., "Fireball Hypothesis Describing the Reaction Front and Shock Wave Behavior in Liquid Propellant Explosions," Technical Paper No. 387, Florida Engineering and Industrial Experiment Station, Vol. XXI, No. 8, August, 1967.

22. Air Products, Inc., "Static Charge Generation," ProjectI, Contract No. AF 18(600)-1771, February, 1959.

23. Loeb, L.B., "Static Electrification," Progress in Dialectrics, Vol. 4, Academic Press Inc., pp. 249-309, 1962.

24. Farber, E.A., "Explosive Yield Estimates for Liquid Propellant Rockets Based upon a Mathematical Model," Technical Paper No. 415A: Part VI. Florida Engineering and Industrial Experiment Station, Vol XXII, No. 7, July 1968.

25. Farber, E.A., "Interpretation of Explosive Yield Values Obtained From Liquid Rocket Propellant Explosions," Technical Paper No. 415B, Part VII. Florida Engineering and Industrial Experiment Station, Vol. XXII, No. 7, July, 1968.

26. Workman, E,J. and Reynolds, S.E., "Freezing Potentials," Physics Review, 78, p. 254 (1950).

27. Welch, J.E., et. al, "The MAC Method," Los Alamos Scientific Laboratory Report LA-3425 (March, 1966).

28. San Martin, R.L., "A Theoretical Investigation and Experimental Verification of the Mixing of Insoluble Liquids," Ph.D. Dissertation, University of Florida, March, 1969.

29. Willoughby, A.B., et. al., Problems Involved in Assessing the Explosive Hazards of Liquid Bipropellant Systems," Project PYRO, Contract No. AF 04(611)-9558, September, 1964.

30. Farber, E.A., "Prediction of Explosive Yield and Other Characteristics of Liquid Propellant Rocket Explosions," Technical Paper No. 448, Part VIII, Florida Engineering and IndustrialExperiment Station. Vol XXIII, No. 11, November, 1969.

31. Eichel, F.G., "Electrostatics," Chemical Engineering, March 13, 1967.

32. Yates, G.B. and Perl, A.R., "Spark Ignition Parameters for Cryogenic Hydrogen in Oxygen and Nitrogen Mixtures," Advances in Cryogenic Engineering, Vol 10, 1967.

33. Bonzon, C.F., "Generation of Static Electricity Caused by the Mixing of Insoluble Fluids", Ph.D. Thesis, University of Florida, December 1970.

34. Ernsberger, F.M., "Mechanism of Frictional Electrification of Dialectric Liquids," Journal of Applied Physics, Vol. 27, No. 4, pp. 418-419 (April, 1956).

35. Quist, J.D., and Washburn, E.R., "A Study in Electrokinetics," Journal of the American Chemical Society, Val. 62, No. 11, pp. 3169-3172 (November, 1940).

36. Gemant, A., "Electrical Properties of Hydrocarbons," in A. Farkas, Physical Chemistry of Hydrocarbons, Vol. I. Academic Press, Inc., New York, Chap. VI, pp. 215-240, 1950.

37. Goodwin, D.W. and MacFadyen, K.A., "Electrical Conduction and Breakdown in Liquid Dielectrics," Proceedings of the Physical Society (London, Section B., Vol. 66, No. 2, pp. 85-96 (February, 1952).

38. Meek, J.M. and Craggs, J.D., Electric Breakdown of Gases, Oxford University Press, London, 1953.

39. Lewis, B. and Von Elbe, G., "Combustion, Flames and Explosions of Gases, Academic Press, Inc.; New York, 1951.

40. MacKeown, S.S., and Wouk, V., "Electrical Charges Produced by Flowing Gasoline," Industrial and Engineering Chemistry, Vol. 34, No. 6, pp. 659-654 (June, 1942).

41. Loeb, L.B., Static Electrification, Springer-Verlag, Berlin, 1958.

42. Farber, E.A., et al. "Feasibility Study to Explore the Explosive Effects of Liquid Propellants to Define the Mathematical Behavior of Physical Processes Involved," Final Report, Phase I, Contract No. NAS10-1255, University of Florida, February, 1965.

43. NASA/USAF Liquid Propellant Blast Hazards Program, Projet PYRO Monthly Progress Reports, AF Rocket Propulsion Laboratory, Research and Technology Division, Edwards, California.

SAFETY OF PREPACKAGED LIQUID PROPELLANT ROCKETS

FORREST S. FORBES
LT HOWARD M. WHITE

AIR FORCE ROCKET PROPULSION LABORATORY
EDWARDS, CALIFORNIA 93523

PRECEDING PAGE BLANK

SAFETY OF PREPACKAGED LIQUID PROPELLANT ROCKETS

By F. S. Forbes
Lt H. M. White

AIR FORCE ROCKET PROPULSION LABORATORY

ABSTRACT: Although liquid propelled missiles and rocket vehicles have been well proven for many of the Air Force Space Missions, and NASA's Apollo program, there is a reluctance to accept liquid rocket engines for tactical weapons.

Many publications overlook the important safety consideration designed into liquid rocket missiles during the development phase. This paper describes the design features and the extensive testing and evaluation procedures that are used to assure safety. A review of Bullpup, Lance, Condor safety criteria, classification tests, and experience is presented.

The paper also discusses storable liquid propellant characteristics, experience gained by the Air Force Rocket Propulsion Laboratory in the on-going, in-house, liquid propellant storage program, and industrial experience with liquid rocket propellants and similar chemicals.

INTRODUCTION: In the quest for higher performing missiles, especially when maneuvering capability and thrust modulation are required, there is a constant evaluation to determine the most suitable propellants. Solid propellants are usually selected for air-launched and tactical applications; however, for some missions, liquid propellants offer higher performance and greater flexibility in energy management. Even though liquid rocket engines have seen operational use for over 27 years, there is still a strong belief that liquid propellants present undue hazards requiring excessive precautions to assure safe operations. Experience has shown that prepackaged liquid propellant missiles can meet the operational requirements of handling ease, storability, and safety.

The prime criteria for selection of a propellant, liquid or solid, is its ability to meet the mission requirements of performance, storability, and handling. Cost, though important, is a secondary consideration. Propellant

costs alone are not a controlling selection parameter, but rather the total cost of the missile system including development and production costs, and all unique handling equipment and environmental control facility costs. Special procedures and equipment required to assure adequate safety to personnel and facilities must also be included in the total cost picture. All propellants can be used safely, thus safety per se, should not be a controlling selection parameter. The cost of providing a safe system must be considered, however.

Liquid rocket propellants are being safely used. Safety has been designed into the current missiles and space vehicles. Of course, personnel need to be trained to treat liquid propellants with proper respect, but this is true of solid propellants and ordnance items also. Prepackaged liquid propellant missiles can be filled and sealed at the manufacturing plant, eliminating the need for field servicing and special ground support equipment. Such pre-packaged liquid propellant rockets can be handled as a round of ammunition.

HAZARD ASSESSMENT

Liquid propellants in reality, have been well accepted in many applications as indicated in Table I. The reliability of the man-rated storable propulsions in the Apollo service module, command module, and LEM vehicles has been outstanding. Bullpup is an example of a mass produced pre-packaged missile. It is a safe, rugged, reliable unit, capable of being handled without maintenance. Pre-packaged liquids have been stored, handled, and used at Air Force installations, Naval shore facilities, and aboard Navy ships without serious incidents.

LIQUID PROPELLANT APPLICATIONS

BALLISTIC MISSILES	CORPORAL REDSTONE ATLAS THOR	JUPITER MINUTEMAN (PBPS) TITAN I TITAN II
LAUNCH VEHICLES	TITAN III	SATURN
SPACE VEHICLES	SURVEYOR MARINER INTELSAT	AGENA DELTA APOLLO LEM
TACTICAL ROCKETS	LAR MALAR BULLPUP LANCE	
DEFENSIVE MISSILES	BOMARC NIKE AJAX	

TABLE I

All liquid propellants have certain characteristics that must be appreciated and understood for safe use; the same is true of solid propellants, ammunition, and industrial chemicals. Many of these materials are toxic, some are corrosive, and some will easily burn or contribute to a combustable situation.

Liquid propellants of current interest for pre-packaging are shown in Tables II and III.

PRE-PACKAGEABLE FUELS

PROPERTY \ PROPELLANT	MAF-1	HOTSGEL	MMH	UDMH	MHF-3
FREEZING POINT (°F)	< -148	< -65	-62	-71	-65
BOILING POINT (°F)	171	180	190	144	193
SPECIFIC GRAVITY @ 77°F	0.87	1.5	0.87	0.8	0.9
TOTAL VAPOR PRESSURE PSIA @ 60°F	1.4	0.6	0.6	2	0.6

TABLE II

PRE-PACKAGEABLE OXIDIXERS

PROPERTY \ PROPELLANT	NITRIC ACID IRFNA	NITROGEN TETROXIDE N_2O_4	CHLORINE TRIFLUORIDE ClF_3	CHLORINE PENTAFLUORIDE ClF_5	BROMINE PENTAFLUORIDE BrF_5
FREEZING POINT (°F)	-77	11.8	-105	-153	-80
BOILING POINT (°F)	104	70	53	8	104
SPECIFIC GRAVITY (@ 68°F)	1.56	1.45	1.8	1.79	2.5
TOTAL VAPOR PRESSURE (PSIA @ 68°F)	2	14	21	42	4

TABLE III

Nitric acid and nitrogen tetroxide are operational oxidizers. Chlorine trifluoride and the other halogen materials offer higher performance and have undergone considerable development during the past several years. These energetic oxidizers have caused the most apprehension among missile designers and safety personnel, whereas liquid fuels are considered completely storable and present only minimal handling problems.

The popular image of liquid propellant systems is that they leak. However, it has been demonstrated that leaks can be avoided by the use of proper fabrication techniques and quality control procedures. Further treatment of this subject is presented later in this paper. Although leaks in operational systems have not produced any disastrous consequences, we must recognize the potential hazards of toxication, fire and explosions. Table IV depicts the relative hazards for several propellants and combinations. Due to the high reactivity of halogen oxidizers, any leaks or spills are likely to result in a fire, precluding the collection of an explosive atmosphere. Liquid propellants in use or recommended for new applications are not explosives. Liquid oxidizers will not explode or detonate by themselves.

CONSEQUENCES OF PROPELLANT RELEASE

PROPELLANT	TOXICATION	FIRE	EXPLOSION
HALOGENS	●	◆	▼
NITROGEN OXIDES	●	●	▼
OXYGEN	▼	●	▼
HYDRAZINES	◆	●	●
HYDROGEN	▼	●	◆
KEROSINE	▼	●	●
HALOGEN HYDRAZINE	●	◆	▼
NITROGEN OXIDE HYDRAZINE	●	◆	●
OXYGEN (HYDROGEN KEROSINE)	▼	◆	◆

HIGH ◆
INTERMEDIATE ●
LOW ▼

TABLE IV

Neither will a liquid fuel explode or detonate in the liquid state. Fuel vapors mixed with air following a spill will burn or explode just as automobile gasoline under similar circumstances. Tests conducted under Project Pyro (1) showed that large explosive yields greater than 100% TNT equalments, can occur with the cryogenic systems (liquid oxygen/kerosene and liquid oxygen/liquid hydrogen) upon gross mixing with subsequent ignition. However, the tests with the storable propellants, nitrogen tetroxide/hydrazine + UDMH, resulted in TNT equivalents on

the order of 5%. TNT equivalents are a poor measuring stick for liquid propellants because of the great difference in the time/pressure curves compared with TNT; however, the relative safety of hypergolic system is demonstrated.

Looking at the relative toxication hazards, the halogens do not present as serious a problem as does hydrazine, because their highly irritating odor is much less tolerable at the same toxic hazard level. The common measure for assessing the toxic hazard of materials is the threshold limit value (TLV). Established by the American Conference of Governmental Industrial Hygienists, these values "represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect. The values listed refer to time-weighted average concentrations for a normal work day" (2). The practical event of a leak or small spill during an accident is not considered. Emergency Exposure Limits (EEL) are established for a few propellants for the purpose of limiting exposure and quantity of material present to protect individuals in a health compromising situation, such as a gross spill.

Table V lists the TLVs of several propellants and common industrial chemicals. The halogens (including chlorine) and the nitric oxides (nitric acid and N_2O_4) have intolerable odors which one can readily detect and will immediately attempt to avoid. The odor of hydrazine is more easily tolerated. Carbon tetrachloride and vinyl chloride have a pleasant odor giving a person the false sense of security. Parathion, a common insecticide, has almost no odor. Thus one can receive excessive dosages of such agents without discomfort or warning. Nitrogen asphyxiation produces no

PROBABILITY OF INVOLUNTARY TOXICATION

RELATIVE TOXICITIES OF SELECTED CHEMICALS

CHEMICAL	TLV (PPM)	PROBABILITY
HALOGEN PROPELLANTS	0.1	LOW
NITROGEN OXIDES	2.5-5.0	LOW
HYDRAZINES	0.2-1.0	HIGH
CHLORINE	5.0	LOW
CCl_4	25	HIGH
VINYL CHLORIDE	500	HIGH
PARATHION	0.1	HIGH
CW AGENTS	0.001-5.0	HIGH
CO	100	HIGH
N2	ASPHYXIANT	HIGH

TABLE V

warning; for this reason nitrogen can be considered highly hazardous. There have been several fatalities in the rocket community because of nitrogen asphyxiation. For instance, within the past 19 years at the AFRPL, two contractor deaths occurred because of nitrogen asphyxiation, while 5 other workers lost their lives in construction accidents, and one due to a vehicle test. There have been no fatalities in which propellants played a part. Table VI also shows the Laboratory record on lost time personnel injuries.

There are a number of toxic industrial chemicals used in enormous quantities in this country. Table VII is presented to show that considerable "know-how" exists for the safe manufacture, shipping and handling of hazardous materials. The potential problems of liquid propellants are no worse than that experienced daily in the chemical process industries.

AFRPL EXPERIENCE

FATALITIES IN 19 YEARS OPERATION

• CONSTRUCTION	7
• VEHICLE TEST	1
• PROPELLANT RELATED	NONE

REPORTABLE LOST TIME (SINCE JANUARY 1969)

• MOTOR VEHICLE	5
• MISC	8
• PROPELLANT RELATED	1

TABLE VI

SAFETY MANAGEMENT

Safety can be designed into the liquid propellant missile, test facilities and ground support equipment. Compatible materials must be used. The systems must be clean and, when necessary, passivated. Proper quality control of the materials, cleaning agents and propellants must be exercised. Mechanical joints should be minimized through

ROCKET INDUSTRY EXPERIENCE

PROPELLANT	DOT CLASSIFICATION	SHIPPING CONTAINERS	QUANTITY (1967 1971)
F_2	FLAMMABLE COMPRESSED GAS	TRAILERS MS	272,300 LBS
ClF_3 ClF_5	CORROSIVE LIQUID	TON CYLINDERS MS	135,000 LBS
N_2O_4	POISON A	TANK CARS SS AL	60,000,000 LBS
IRFNA	CORROSIVE LIQUID	TANK CARS AL	3,900,000 LBS
HYDRAZINES	CORROSIVE OR FLAMMABLE LIQUID	DRUMS OR TANK CARS SS	35,500,000 LBS

SELECTED CHEMICALS			INDUSTRIAL USE YEAR
CHLORINE	NONFLAMMABLE GAS	TANK CARS MS	14.4×10^9 LBS
PARATHION	POISON A OR B	DRUM (110 GAL) MS AL	10^9 LBS TOTAL PESTICIDES
VINYL CHLORIDE	FLAMMABLE LIQUID	TANK CARS SS	$2.5 \cdot 10^9$ LBS
NITROBENZENE	POISON B	TANK CARS SS AL	
ANHYDROUS HF	CORROSIVE LIQUID	TANK CARS SS	$0.4 \cdot 10^9$ LBS

TABLE VII

the use of welded fittings. Double failure hardware design and use of burst discs are techniques which should be considered. Non-destructive inspection techniques must be used to locate flaws in weld areas, high stress areas, and in critical components. A proper philosophy must be adapted to assure a trouble-free system. If, during the development and pre-productive phases, leaks or other failures occur, the question must be asked: why did not the inspection procedure locate the fault before failure occurred?

Personnel training is necessary. Mistakes can be avoided if personnel are familiar with the system and the operating procedures and regulations. The technique of frequent "dry runs" will help maintain a high level of competence. The nature of propellants and hazard control procedures should be presented to the personnel in a manner to instill confidence, and not fear.

Pre-packaging at the point of manufacture eliminates the complexities of logistics involved with field servicing and the related ground support equipment. Quality control of system cleanliness is also assured.

Historically, one of the principal objections to the use of liquids in pre-pack applications has been the real (but more frequently imagined) danger of leakage of toxic propellants. Experience has shown that leakage can be prevented through the use of proper materials, fabrication and quality control techniques.

Perhaps the largest single source of data on propellant leakage and how leakage is related to materials, fabrication techniques, and quality control procedures has been accumulated by the AFRPL as part of their "Packaged Systems Storability Program". In this program fabricated tankage is stored under severe environmental conditions and monitored for leakage. The tankage is fabricated from materials that could be used for pre-packaged applications (i.e, materials with a high strength to weight ratio), and a complete material, process and quality control record is maintained on each tank. In the event of tankage failure through leakage, the tankage is subjected to a post-test failure analysis to determine the cause of leakage, and if that leakage can be related to some occurrance in the fabrication process. The overall scope of the AFRPL storability program is shown in Table VIII, and a partial summation of the positive results of the program is shown in Table IX.

AFRPL PACKAGED SYSTEMS STORABILITY PROGRAM

MATERIAL \ PROPELLANT	N_2O_4	ClF_5	HYDRAZINE FUEL
ALUMINUMS			
2014	38	15	5
2021	5	4	8
2219	14	10	16
7039	4	1	
STEELS			
AM350	6	8	5
17 7PH	7	8	5
A286			5
301 CRYO FOR	14	12	31
TITANIUMS			
6Al 4V	6		8
5Al 2.5 Sn	2		

TABLE VIII

AFRPL EXPERIENCE TO DATE

OVER FIVE YEAR STORAGE DEMONSTRATED

- 2014 ALUM N_2O_4
- 6061 ALUM N_2O_4

OVER FOUR YEAR STORAGE DEMONSTRATED

- 301 CRYO FORM ClF_5
- 301 CRYO FORM N_2O_4
- 7039 ALUM N_2O_4
- 2014 ALUM ClF_5
- 6061 ALUM ClF_5
- 2219 ALUM HYDRAZINE BASED FUEL
- 2219 ALUM N_2O_4

OVER TWO YEAR STORAGE DEMONSTRATED

- 6Al 4V TITANIUM N_2O_4

STORRAGE CONDITIONS

- OXIDIZER 85 F & 85% RELATIVE HUMIDITY
- FUEL: 100 F PLUS & AMBIENT HUMIDITY

TABLE IX

The program has demonstrated that conventional TIG welding is an acceptable means of material joining, provided that a proper quality control procedure is developed. This quality control plan should be complete and thorough. The most vital part of the quality control effort is that concerned with the acceptance of the fusion welded joint. AFRPL experience has shown X-ray, dye penetrant, and helium mass spectrometer leak testing are all necessary to insure that the fusion welded joint is acceptable and leak free.

Preparedness is an important part of safety management. The possibility of a creditable accident must be considered. Damage control tests have been conducted by:

Naval Weapons Laboratory[3]
Naval Weapons Center
AFRPL
Allied Chemical Corporation
Rocketdyne[4]
Reaction Motors, Thiokol Chemical Corporation
Army Chemical Center

Fires can be suppressed, and spills controlled. Water is the best agent

for all of the propellants considered for pre-packaging. When applied as a high pressure fog, water is particularly effective for knocking down propellant fumes. Dry chemicals, such as calcium fluoride, are effective for controlling small spills of chlorine trifluoride and related oxidizers. The resulting residue is non-toxic, and is easily disposed.

PACKAGED LIQUID PROPELLANT ROCKET EXPERIENCE

Prior to acceptance of propulsion units for operational usage, extensive test programs are conducted to establish that the systems are safe for personnel to handle and operate under all field or shipboard conditions. Storage, handling and transportation procedures are developed, and hazards classification determined.

Table X lists the pre-flight rating and qualification tests for the Bullpup. All missile systems are subjected to similar tests, modified to simulate the specific operational characterization of the using Service. Results of each test are fully evaluated, and any design deficiencies corrected. Specific tests are repeated until final acceptance is assured.

PRE-FLIGHT RATING AND QUALIFICATION TESTS

1 EXTREME TEMPERATURE FIRING	16 HYDROSTATIC BURST
2 THERMAL CYCLING	17 RESTRAINED MISSILE FIRING
3 TEMPERATURE GRADIENT	18 SIMULATED CATAPULT ARRESTED LANDING
4 ALTITUDE	19 CENTRIFUGE
5 VIBRATION	20 ADDITIONAL IGNITER TESTS (a) FORTY FOOT DROP (b) JOLT & JUMBLE
6 JET PATTERN & BLAST PRESSURE	
7 FREIGHT SHIPMENT	
8 SIX FOOT DROP TEST (UNCRATED UNITS)	21 AUTO AUTO IGNITION RESISTANCE IGNITER SOLID CHARGE AND BOOSTER
9 LONG TERM STORAGE	
10 RAIN	
11 HUMIDITY	22 GUNFIRE TESTS
12 SALT SPRAY	23 EXPLOSIVE IMPACT
13 ACCELERATION & DECELERATION	24 EXTERNAL IGNITION
14 STATISTICAL FIRING	25 40 FOOT DROP TEST
15 ATTACHMENT LOADING	26 SLOW AND RAPID HEAT TESTS

TABLE X

The experience with several pre-packaged liquid propulsion systems has been noteworthy. Probably the first application of the pre-packaged concept is the LAR. This technology was later utilized in the highly successful Bullpup missile, and is now being applied to the Lance. Condor was to use the high energy oxidizer chlorine trifluoride, which would have represneted a major advancement in the pre-packageability of liquid propellants. Unfortunately, the state-of-the-art was not quite ready for systems development. The Minute Man Post-Boost Propulsion System (PBPS) used more conventional propellants and has not encountered any propellant problems.

Titan II is the classic example of propellant leakage. It is not pre-packaged, and its problems are unique to its size. The difficulties encountered simply do not exist in the small, factory-loaded missiles. These systems are further discussed below.

LAR STORAGE STUDIES

In 1955, the Navy filled several 5 inch diameter liquid aircraft rockets (LAR) with IRFNA and a hydrazine fuel and placed them in desert ambient and controlled temperature storage. The concentric propellant tanks were made of 6061 aluminum alloy with end closures of 356 aluminum alloy. The ullage balonet was made of 1100 aluminum.

A total of seven long-term storage tests were made, as indicated in Table XI. The pressures developed were generally low and in all cases stable after a few months.

LAR STORAGE TESTS

OXIDIZER IRFNA (21 LB) FUELS. ALCOHOL, HT 32 & UDMH

NO.	TEMP	STORAGE TIME, YR	COMMENTS
1	165 F	2.4	PROVED EFFECT OF HF
2	DESERT AMBIENT [a]	8.0	GOOD CONDITION
3	DESERT AMBIENT	8.5	GOOD CONDITION
4	DESERT AMBIENT [b]	11.5	LITTLE CORROSION c
5	DESERT AMBIENT	12.0	ALUMINUM SALTS c
6	DESERT AMBIENT	8.5	GOOD CONDITION
7	DESERT AMBIENT [b]	11.5	GOOD CONDITION

a) 0 TO 115 F
b) INCLUDES 461 DAYS AT 70 F
c) OXIDIZER TANK

CONCLUSION SLOW CORROSION BY IRFNA OCCURS. BUT NO NEAR FAILURES WERE OBSERVED

TABLE XI

Test No. 1 was made to check the effect of increasing the IRFNA corrosion inhibitor (HF) from 0.6 to 1.0. After 2.4 years at 165°F, the tank was opened and inspected. "Crevice Corrosion" was decreased markedly by the Higher HF concentration.

Test No. 2 was terminated at 8 years, because the 1/8 inch aluminum line to the pressure gage had corroded. Both the oxidizer and fuel tanks were in good condition. The other tests were discontinued at the time indicated in Table XI, and the tanks inspected. The oxidizer tank surface had the usual grey fluoride coating and appreciable volume of crystalline solids $(Al(NO_3)\cdot\%H_2O)$ were present in the acid. Expulsion of the oxidizer from Test 6 was accomplished through a 1/8' orifice to simulate the flow of an actual LAR firing.

Naval Weapons Center personnel, upon reviewing the test results [5], concluded that:

a. IRFNA (type IIIA) can be stored under desert ambient conditions in aluminum tanks for more than 10 years.

b. Corrosion of the aluminum by the IRFNA does occur at a slow rate, but no near failures were observed in any test, and the aluminum salts did not appear to interfere with oxidizer expulsion through a 1/8' orifice.

c. The hydrazine fuels caused no corrosion of the aluminum tanks.

BULLPUP

The Bullpup is a packaged liquid rocket developed by the US Navy, and is in operational use by both the Navy and the US Air Force. It was introduced to the fleet in 1960. This missile utilizes a simple, dependable, pressurized propellant feed system to force the propellants from hermetically sealed tanks to the combustion chamber. A solid propellant gas generator provides the gases needed to pressurize the tanks and to inject the propellants into the combustion chamber. Inhibited red fuming nitric acid (IRFNA Type IIIA) is the oxidizer. The mixed amine fuel (MAF-1) consists of diethylenetiamine and UDMH. In 1962 five fuel leaks were found among the Bullpups aboard the USS Ticonderoga.[6] The epoxied fuel fill port was failing. The leaks were, in most cases, extremely small, and only a few so-called leaking engines emitted any fuel. Most of the condition was one of odor and stain. All missiles in service were retrofitted with a double closure. In new production units the fill port was welded, the same as the oxidizer port. Three oxidizer leaks have occurred out of the 48,990 liquid propulsion systems that have been manufactured in several configurations during the past eleven years. Some of the inventory are now reaching an age of nine years, far beyond the original design life of five years, and are still operational. In addition to the leakers noted above, one missile was punctured when another was dropped on it, and two leaked and caught fire in a magazine at a Naval yard. Five other Bullpups were damaged or destroyed, and 19 sustained no damage. These missiles were part of a group that were immersed when a magazine aboard a ship was inadvertantly flooded. In another incident, a number of Bullpups were caught in a serious fire and detonations involving solid propellant rockets and bombs. The damaged Bullpups burned, but did not contribute to the explosive yield of the exploding ordnance. There have never been any personnel injuries, nor any property damage resulting from the Bullpup propellants since fleet acceptance

(Table XII). Personnel have been injured when missiles have fallen, or when being swung on hoists.

The Navy's goal of delivering in mass production a safe, rugged, reliable unit capable of being handled safely and without maintenance, has been achieved. Ships and Air Force units have been transferring, storing and using packaged liquid Bullpups with extremely few problems.

BULLPUP EXPERIENCE

IN ELEVEN YEARS WITH 48,990 MISSILES:

- MINOR FUEL LEAKS-NONE SINCE 1962
- THREE OXIDIZER LEAKERS
- ONE PUNCTURE (PERSONNEL ERROR)
- ONE FIRE

NO PERSONNEL INJURIES OR PROPERTY DAMAGE!

OPERATIONAL LIFE OF 9 YEARS DEMONSTRATED!

TABLE XII

LANCE

The Lance propulsion system, developed by the Army Missile Command, is pressure-fed, utilizing pre-packaged, liquid propellants. The missile feed system consists of two propellant tanks in tandem, the forward tank containing the fuel (UDMH) and the aft tank containing the oxidizer (IRFNA). Expulsion of these two hypergolic propellants into the engine is effected by two pressure-driven pistons. The fuel is piped from the forward tank through the oxidizer tank in a fuel transfer tube to the engine. The oxidizer is forced directly into the engine assembly. The entire system is designed to operate between the limits of -40°F and +140°F, and to be stored between -65°F and +155°F. This missile is not yet operational; however, the results of development programs can be discussed. The Lance engineering development test program had five major categories of tests: feed system, propulsion system, developmental flight tests, operational flight tests, and hazards classification. As of April 1971, 56 feed system and 86 propulsion system tests were made. In addition, 112 developmental and 7 operational flight tests had been accomplished. During flight testing of the prototype model, two missiles exploded in the launcher after the fire switch was closed. As a result of these failures, the missile was subjected to an extensive evaluation which pin-pointed the failure mode. Re-design of the identified faulty components was then accomplished and followed by 10 feed systems, 32 propulsion systems, and 54 flight tests without any repetition of such failures.

Additionally, personnel-launcher separation distances during firing were established to minimize exposure of personnel to this type of hazard potential.

Inherent safety features have been built into the total Lance system. Some are mechanical devices, others are electrical safeguards. The following is a partial list:

a. Drop Indicators - to record excessive rough handling

b. Propellant Leak Indicators - to detect structural or seal failure

c. Anti-Propulsion Unit - to prevent inadvertent or unauthorized launch

d. Dead Space Ports - for inspection of piston seals.

Safety is designed into the missile itself, as well. The propellant tanks are constructed with well-proven compatible alloys, and proof tested. A shipping container is used to protect the missile during transportation and storage.

The hazards classification tests have been conducted to define the personnel danger zone in the launcher area, and to determine shipping and storage classifications for the Lance Missile System. The simulated warhead detonation test, using 110 pounds of composition C-4 indicated that the propulsion system contribution to the warhead yield is negligible. The missile did not become propulsive during the bon-fire test, nor did any detonation occur. All propulsion systems components remained in the shipping container. During the propulsion system "storage" test, three fully fueled Lance missile propulsion systems packaged in their containers were placed adjacent to each other. Special squib operated valves were installed on the oxidizer and fuel tanks of one system, the "donor". These valves were opened simultaneously, allowing the fuel and oxidizer to mix within the shipping container. The top section of the donor shipping container was thrown about eight feet, but all components of the propulsion system remained within the bottom section. No damage, other than paint discoloration, occurred to the two "receiver" propulsion units. No significant blast pressures were noted.

In summary, a comprehensive series of operational tests, representative of Army field operations for the Lance Missile System, were conducted and all test requirements successfully accomplished[7]. No failures or uncontrollable incidents which jeopardized the safety of personnel were experienced. (Table XIII)

LANCE TEST RESULTS

PRE-QUALIFICATION & QUALIFICATION

- 56 FEED SYSTEM TESTS
- 86 PROPULSION SYSTEM TESTS

FLIGHT

- 119 SUCCESSFUL FLIGHTS
- 2 FAILURES

HAZARD CLASSIFICATION

- UNITS DID NOT BECOME PROPULSIVE
- NO DETONATIONS
- EXCELLENT PROTECTION AFFORDED BY CONTAINER

CONCLUSION

- NO FAILURES WHICH COMPROMISED PERSONNEL SAFETY
- "...LANCE MISSILE IS SAFE FOR TROOPS TO HANDLE & OPERATE TACTICALLY..."

TABLE XIII

CONDOR

The Condor represents the first serious attempt to use a halogen oxidizer in a missile system. Chlorine trifluoride (ClF_3) was selected as the oxidizer, and a mixture of monomethyl hydrazine and hydrazine (MHF-3) as the fuel. Popular rumor states that Condor development was terminated for safety reasons. This is not true, its development was not far enough along for such a decision.

The Condor was to be a pre-packaged missile for the US Navy. Collapsible 1100 aluminum tanks, called Expellodyne, were contained within the rigid missile shell to provide positive expulsion of both propellants. In operation, a solid propellant charge provided the pressurization for a gas generator (GG) liquid monopropellant (MHF-5) which was injected into a thermal bed containing an initiator. The resulting gases pressurized the volume between the outer shell and each Explodyne, collapsing them and forcing the ClF_3 and MHF-3 into the combustion chamber. These two propellants ignite hypergolically. The MHF-5 is also a blend of hydrazine compounds.

Only fourteen developmental units of the Condor liquid propulsion system were fabricated. The results of those that were tested are summarized in Table XIV. It is clear that a number of problems were plagueing the Condor

development; these could not be corrected within cost and schedule restraints. The most serious deficiencies concerned gas generator.

CONDOR SYSTEMS TEST SUMMARY

SYSTEM	TEMPERATURE CONDITIONS F	RESULTS
001	61	OBJECTIVES MET
002	58	OBJECTIVES MET
003	65	PRESSURE LINE BURNED OUT
006	58	OBJECTIVES MET
007	CYCLED	OXIDIZER EXPELLODYNE TORE
008	CYCLED, TEST AT 171	OXIDIZER EXPELLODYNE SCREEN BURNED
009	CYCLED	OXIDIZER EXPELLODYNE WELD FAILURE
[illegible](REBUILT)	CYCLED, TEST AT 171	GG VENT LINE FAILURE
010	CYCLED, TEST AT 77	OBJECTIVES MET, SOME GG HANG UP
011	CYCLED, TEST AT 74	OBJECTIVES MET, SOME GG HANG UP
012	CYCLED	OXIDIZER EXPELLODYNE LEAKED
012A	-48	FUEL EXPELLODYNE FAILURE
013	173	GG FAILURE
014	CYCLED	OXIDIZER EXPELLODYNE LEAKED

NO EXTERNAL LEAKS

TABLE XIV

Although developement of a bootstrap, demand-controlled monopropellant gas generator was accomplished, its pressurization efficiency was poor, even at the relaxed low temperature (-45°F). This resulted in insufficient gas for full duration runs, thus the required total impulse was not achievalbe. The required ignition time was not attained, and the storability of the GG monopropellant MHF-5 was questionable.

The Expellodyne system for positive propellant expulsion was successfully demonstrated; however, the occurrence of holes in two oxidizer units could not be explained. Such holes had never been observed previously by the contractor, Reactor Motors, although hundreds of tanks and expulsion devices had been tested under various R&D programs. It should be pointed out that the observed pin holes did not result in any external leakage; all of the oxidizer was contained within the outer shell. The propellant was subsequently removed from the system without incident.

The design concept of a pre-packaged liquid propulsion system using ClF_3 and MHF-3 was established. However, additional basic development of the propulsion sybsystem must be accomplished before a high performance system meeting the requirements of a tactical missile can be attained.

None of the qualification tests discussed at the beginning of this section were performed on a fully fueled Condor; thus it is not possible to state that there would have been any undue safety problems. There did not appear to be

any serious problems unique to the oxidizer. Positive expulsion problems with the Expellodyne plagued the fuel tank as well as the oxidizer tank. The conclusion of the Navy technical personnel was that the Condor was committed prematurely to system development. (Table XV)

LIQUID CONDOR DEVELOPMENT TERMINATED

1. INSUFFICIENT PRESSURIZATION GAS
2. OXIDIZER EXPELLODYNE PINHOLES
3. INABILITY TO MEET IGNITION TIME
4. INSUFFICIENT TOTAL IMPULSE
5. COST & SCHEDULE CONSIDERATIONS

CONCLUSION:

- PREMATURE COMMITTMENT TO SYSTEM DEVELOPMENT

TABLE XV

TITAN II

No one system has done more to point up the potential leakage problem of liquid propellants than the Titan II weapons system. At the start of the operational emplacement of the Titan II, a rash of leaks developed in the oxidizer tankage of the missile. By and large, the leaks occurred, not in the tank itself, but in the seals and components peculiar to a missile the size of Titan II. (Table XVI). The number of leaks that occurred in the welds of

TITAN II EXPERIENCE

NUMEROUS LEAKS –

- BELLOWS
- JOINTS
- SERVICE OPENINGS
- THIN GAUGE TANKAGE

CORRECTED BY –

- REPAIR
- IMPROVED QC
- CONTROLLED ENVIRONMENT

CONCLUSION –

PROBLEM RELATED TO SIZE

TABLE XVI

the tankage itself was less than 10% of the total number of leaks that occurred in the weapons system. Even these leaks were peculiar to the Titan in that the light skin gauges utilized on the pump feed Titan would not be encountered on a pressure feed pre-package missile; therefore, the chance of a pin hole leak (as was found in the Titan II tank weldments) is greatly reduced in a pre-packaged liquid propulsion system.

The leakage on the Titan II prompted several modifications to the weapons system handling procedures. Principal among them were a lowering of the maximum acceptable leakage criteria and the conditioning of the silos to 20% relative humidity. The vehicle contractor (Martin) found that oxidizer leakage is influenced by humidity, and that below 30% oxidizer vapor leakage would not manifest itself in the form of a detectable liquid leak. These modifications have greatly reduced the leakage problem encountered in this weapons system.

POST BOOST PROPULSION SYSTEM

The Post Boost Propulsion System (PBPS) of the Minuteman III is the most recent example of the use of a pre-package liquid rocket propulsion system. The function of the Minuteman III PBPS to provide the precise increments of velocity for the MIRV capability of this system. The propellants of the system are nitrogen tetroxide (N_2O_4) and monomethylhydrazine (MMH). The propellants are contained in 347 stainless steel bellows inside an A286 stainless steel shell.

The Air Force has embarked on an extensive surveillance program to determine the usable storage life of the PBPS. The program entails the storage testing of ten complete PBPSs, nineteen loaded oxidizer tank assemblies, and nine loaded fuel tank assemblies. All of the above units are monitored for propellant leakage. There has never been a leak in any unit, and some of the oxidizer tank assemblies have been loaded for almost three years. The PBPS system has performed successfully in all cases. (Table XVII)

MINUTEMAN III PBPS EXPERIENCE

OXIDIZER: N_2O_4 FUEL MMH

STORAGE PROGRAM

TEN COMPLETE SYSTEMS (1 YEAR STORAGE)

NINETEEN OXIDERS TANKS (UP TO 3 YEARS)

NINE FUEL TANKS (UP TO 3 YEARS)

RESULTS:

NO LEAKS OR FLIGHT FAILURES

TABLE XVI

CONCLUSIONS

Pre-packaged liquid rockets have been demonstrated to be safe. Otherwise, they would not reach the point of production and acceptance by the using command. Thus, there are no unsafe liquid propelled missiles in the inventory. This is borne out by the fact that the safety records for the Bullpup and the other operational systems, such as Apollo, have been excellent. The leaks problem of the Titan has been aleviated and represents a situation unique to this large, non-prepackaged, system of 1958 technology. The results to date of the storage, qualification, and hazard classification tests of the Lance, and Minuteman PBPS have been very encouraging, indicating that these systems should be highly successful.

The Condor was plagued with problems in the development of the expulsion device and the gas generator. This resulted in the termination of the program because the fixed Condor configuration could not meet the required performance goals. The technology required for an advanced missile of the Condor design was simply not available. The Condor should not have been committed to systems development without further component development.

Liquid propellants considered for pre-packaging are reactive, and the potential hazards associated with them must be recognized and appreciated. Such hazards are different from those of solid rockets and ordnance items; however, the overall hazard is no greater. The nation's chemical process industries manufacture, handle and ship daily in huge quantities, materials just

as hazardous, or more so, than storable liquid propellants.

In spite of the durability and ruggedness which can be achieved by careful design and testing of liquid propellant tankage, the possibility that failure could at some time occur during handling, storage, transportation, however remote, cannot be ignored. Tests have shown that propellant spills and fires can be safely controlled. Comprehensive tests are conducted to assure that missiles are safe in the expected environment for which they are designed, and for creditable malfunctions and personnel errors that might happen. Missiles can only satisfactorily achieve such safety goals through design; the safety features that are built into the propulsion unit. (Table XVIII)

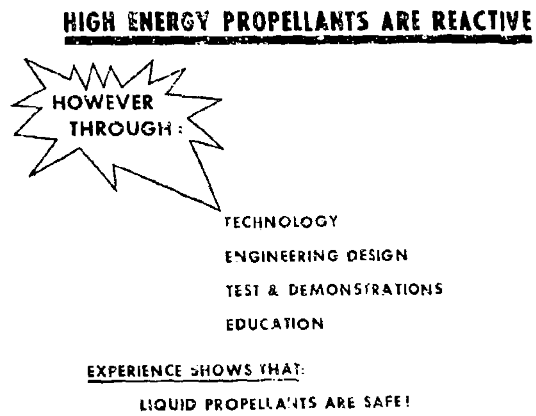


TABLE XVIII

With proper consideration given to technology, engineering design, verified by tests and demonstrations, coupled with personnel training, pre-packaged liquid propellant rockets meet the safety requirements of the Services.

REFERENCES

1. AFRPL-TR-68-92, "Liquid Propellant Explosive Hazards", Final Report Contract AF04(611)-10739, Vol 1, URS Systems Corp., December 1968.

2. Threshold Limit Values for Airborne Contaminants Adapted by ACGIH for 1969.

3. NWL TM No. W-10/65 (NAVAIR RPT No. 5000) "Standardizing Investigations of the Damage Central Aspects of Advanced Packaged Liquid Propulsion Systems", D.A. Wilson & S.W. Palen, U.S. Naval Weapons Laboratory, Aug 1965.

4. AF/SSD-TR-61-40, Research on the Hazard Classification of New Liquid Rocket Propellants, Final Report, Contract AF33(616)-6939. Rocketdyne, Division, NAR, Inc, Oct 1961.

5. LAR Storage Studies, Dean H. Couch, Naval Weapons Center, 10th Liquid Propulsion Symposium 19-21 Nov 1968, CPIA Publication 176, Vol I.

6. "Packaged Liquid Propellant Rocket Engine Safety Considerations for the Fleet". C.H. Cimmick, Reaction Motor Div T.C.C, Presented to ICRPG Hazards Working Group on 7 Dec 1965.

7. Report 7-72220/IR-17, Safety Statement Lance Missile System Production Model, Missiles and Space Division - Michigan, LTV Aerospace Corp, 23 Apr 1971.

LTC Robert L. LaFrenz

SPECIAL SESSION: EXPLOSIVE EXCAVATION

PAPER TITLE: Corps of Engineers' Program of Explosive Excavation

The U. S. Army Corps of Engineers through the Waterways Experiment Station's Explosive Excavation Research Office (EERO), and its predecessor, the Nuclear Cratering Group (NCG), is developing explosive excavation as a cost competitive construction technique for civil works projects and as a valuable tool for military engineering and construction. Explosive excavation utilizes either large point chemical or nuclear charges to break up the material, and in most cases to also remove it from the excavation. See Figure 1. Development of this technique began as a joint Corps of Engineers-Atomic Energy Commission program to develop nuclear excavation. The Nuclear Cratering Group used large chemical high-explosive charges of up to 85 tons of nitromethane during the period 1962-69 as modeling charges for the AEC's nuclear excavation tests. During the conduct of these modeling tests, it became obvious that explosive excavation using chemical high explosives offered the possibility of both cost and time advantages over conventional construction techniques on small to medium-sized projects.

RECENT DEMONSTRATIONS OF THE TECHNIQUE

● CHANNEL - The first project designed specifically as a demonstration of chemical high-explosive excavation was detonated in October 1969 at Fort Peck, Montana. It was designated the Reservoir Connection Experiment and culminated a series of tests begun in 1966 and originally planned as modeling experiments for nuclear detonations in clay shale.

PRECEDING PAGE BLANK

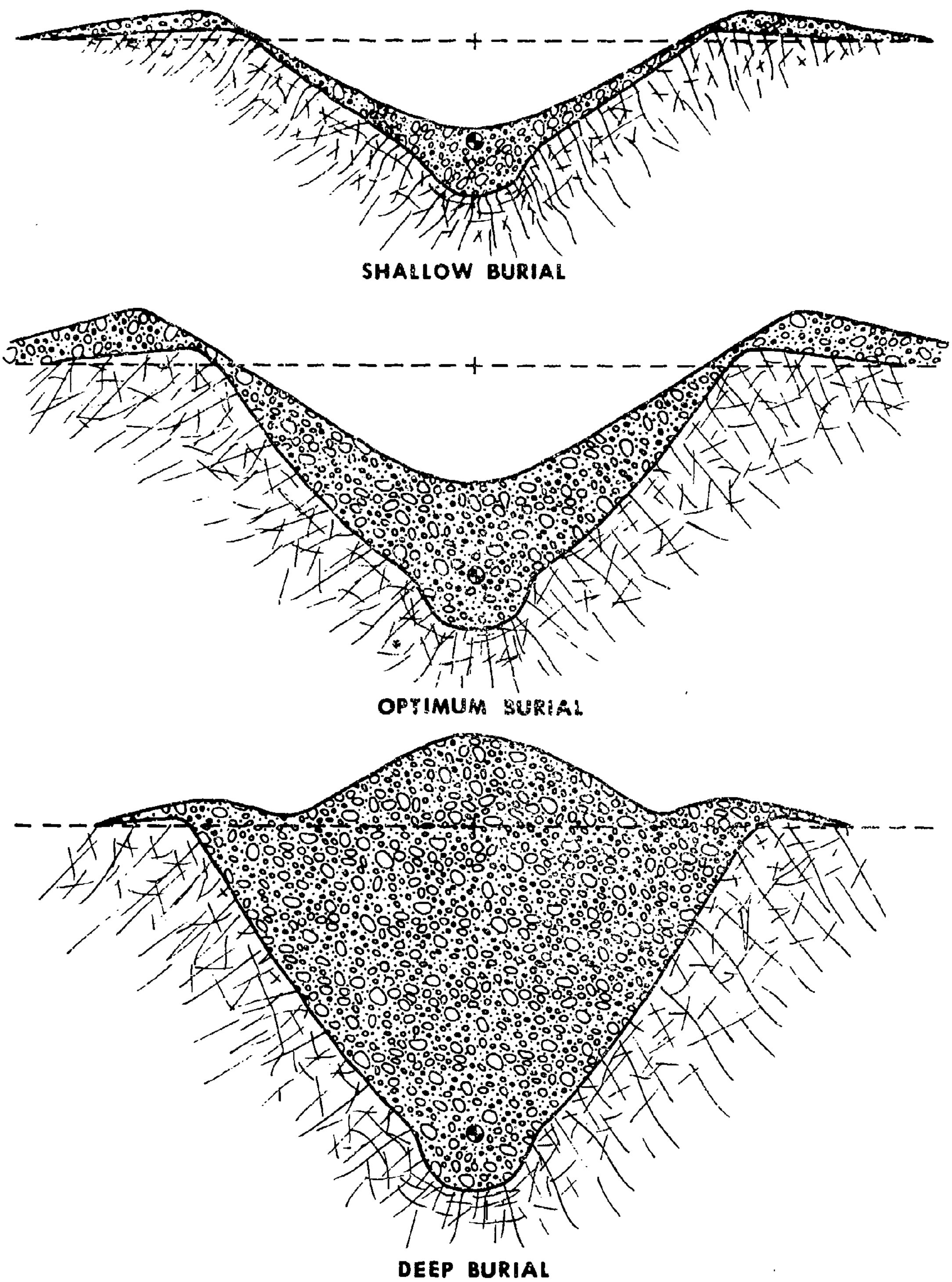


Figure 1. Crater Cross Sections

The primary objective of the reservoir connection experiment was the development of a chemical explosive excavation capability. An aluminized ammonium nitrate slurry (blasting agent) was used for the first time in a major row-cratering experiment. Such a slurry with 10 to 20% aluminum is approximately 1.5 times as effective for cratering purposes as TNT, ammonium nitrate with fuel oil (ANFO), or nitromethane. The cylindrically-shaped charge had a length-to-diameter ratio of one, but it has since been determined in small scale tests that this ratio can be increased to at least six without a significant reduction in cratering efficiency. The larger the ratio, the smaller the drill hole and consequent emplacement costs.

A total of 70 tons of the slurry explosive was used to connect the previously detonated row to the Fort Peck reservoir, with the largest charge containing 35 tons. The resultant channel, consisting of the previously excavated row craters and the Reservoir Connection Experiment, shown in Figure 2, is approximately 1370 feet long and 150 feet wide at water level, and has an average depth of 26 feet along the centerline.

The experiment demonstrated that the design of a single row of cratering charges to produce a water conveyance channel is relatively simple and offers definite cost advantages.

- HARBOR - The use of explosive excavation in April 1970 to produce an entrance channel and berthing basin for a small boat harbor at Kawaihae Bay, Hawaii, marked the first use of this technique in connection with a Civil Works project of the Corps of Engineers. Because no experience was available for underwater cratering in coral, a test series of four 1-ton charges and one 10-ton charge were detonated singly in November 1969. The craters produced by these calibration tests were unique. Instead of a conventionally shaped crater with lips, a wide saucer-shaped crater with no lips was obtained.

Figure 2. Explosively Excavated Channel at Fort Peck

This was due to the consolidation and crushing of the weak porous coral, the interaction of the water with the ejecta, and the washing action as the water and ejecta refilled the crater. This wide, shallow configuration allowed a less expensive design than one predicated on typical dry crater shapes, which had a great deal of overdepth.

The final design for this project, called Project TUGBOAT, is shown in Figure 3. The design entrance channel has a minimum width of 130 feet. The berthing basin is 300 feet square at the design depth of at least 12 feet below mean lower low water. Twelve 10-ton charges buried at an average depth of 35 feet below the coral bottom were used in the configuration shown. Eight of these charges were used for the entrance channel and four for the berthing basin. These criteria were met or exceeded in all areas by explosive excavation.

Although planned specifically as a demonstration project for chemical high-explosive excavation, certain aspects of the project and the many associated technical programs of airblast, ground shock, wave formation and environmental effects provided data which would be applicable to a nuclear excavated harbor. Although Project TUGBOAT completely accomplished its objective, different dynamic crater formation phenomena are expected when cratering underwater in a material more competent than coral. A test project of this type is under consideration.

● RAILROAD CUT - Because many Corps of Engineers Civil Works projects require highway or railroad relocations, a project of this type was desired to prove the applicability of explosive excavation to road cuts. The requirement to relocate a railroad at the site of the Albuquerque Engineer District's dam and lake project on the Purgatoire River near Trinidad, Colorado, provided such an opportunity. The on-site material was weak interbedded sandstone and shale with 5 to 10 feet of overburden. Extensive

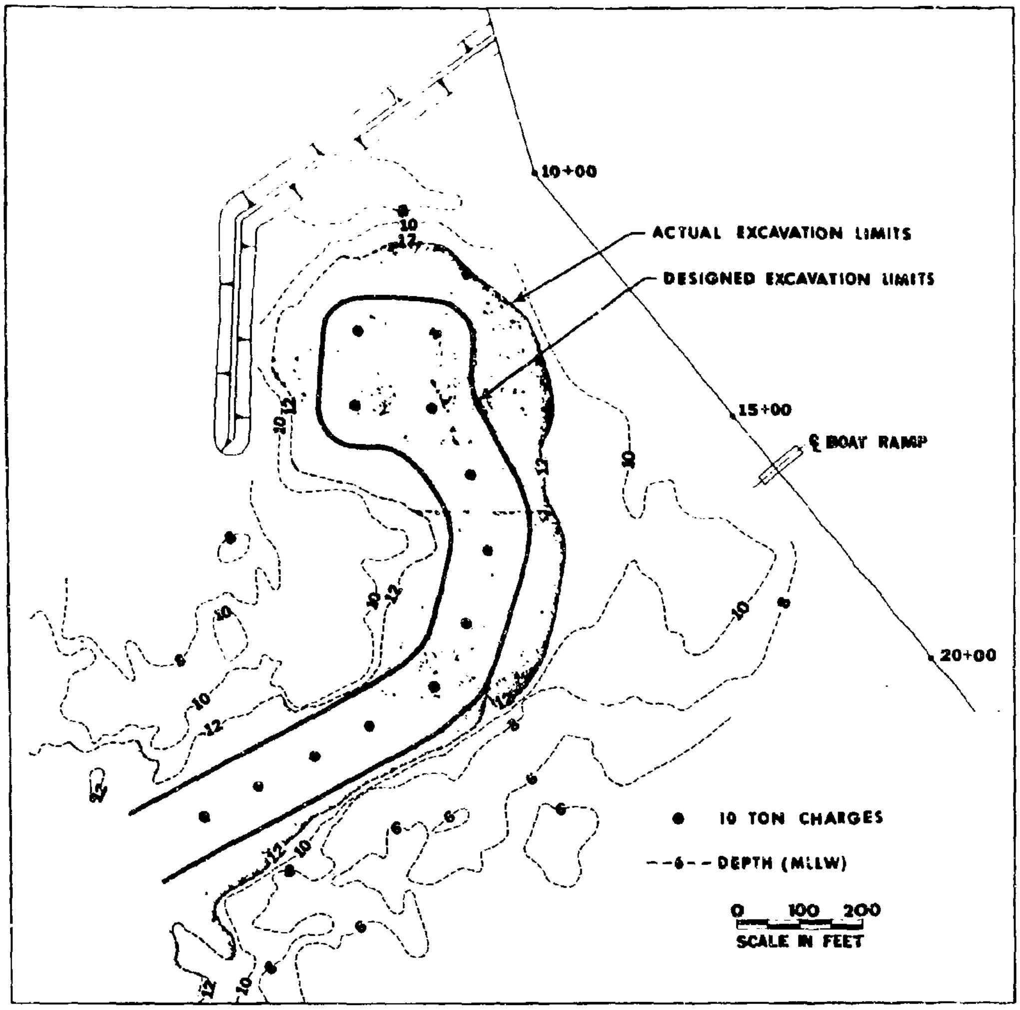


Figure 3. Final Design and Results of Project TUGBOAT

explosive excavation investigations were undertaken, including a comparison of full charge diameter drilling, underreaming, and hole-springing as emplacement methods; a comparison of ANFO and slurry explosives; an investigation of the effects of different charge spacing in a row; a determination of the effect on cratering efficiency of sequential detonation of charges in a row (to reduce ground shock and airblast); the results of single and double rows detonated on a sidehill, and a comparison of simultaneously and sequentially detonated double rows.

The final experiment was a railroad cut detonation executed on 16 December 1970, which produced a 400-foot cut for the railroad realinement. The project called for a maximum excavation depth of 20 feet with a width of 46 feet at the railroad subgrade elevation. Conventional excavation of the cut would have required the removal of approximately 13,000 cubic yards of material. The detonation consisted of two sequentially fired rows of explosives with 44 tons of aluminized ammonium nitrate slurry in thirty-two 1-ton and 2-ton charges. A typical cross section of the resulting excavation is shown in Figure 4. Results very close to the design cross section were achieved, including relatively flat slopes. The completed cut after minor dressing is shown in Figure 5. The sequential detonation removed considerably more material from the cut than a simultaneous detonation of double rows; thus reducing fallback thickness and consequent settlement problems within the crater.

CURRENT PROJECTS

● RAILROAD CUTS - Two additional railroad cuts in sandstone and shale are planned at Trinidad, Colorado, with explosive excavation. One cut 500 feet long will utilize "mounding". This concept and design are shown in Figure 6. The term "mounding is used to describe explosive excavations when

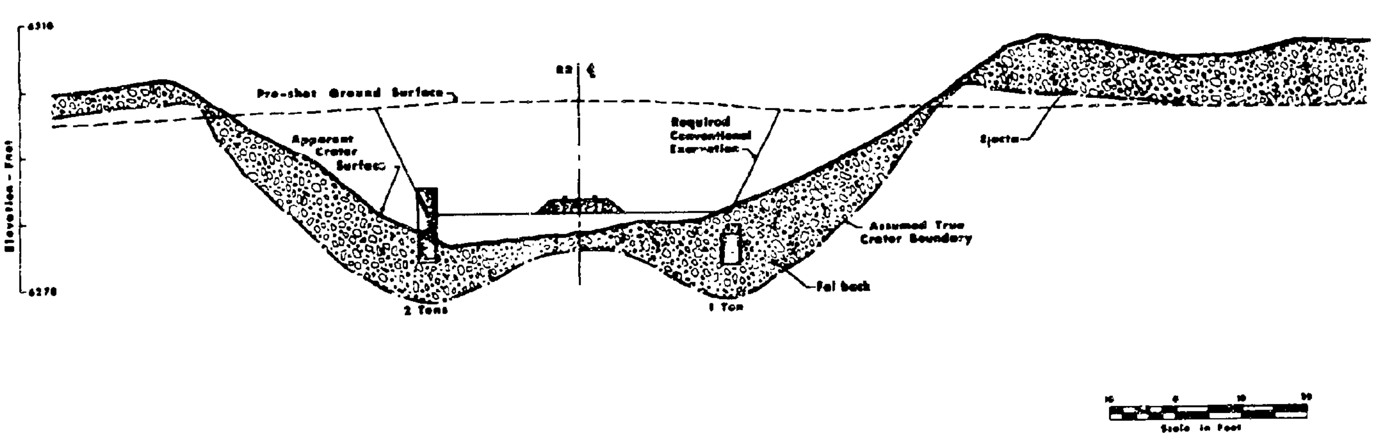


Figure 4. Typical Cross Section of Trinidad Railroad Cut

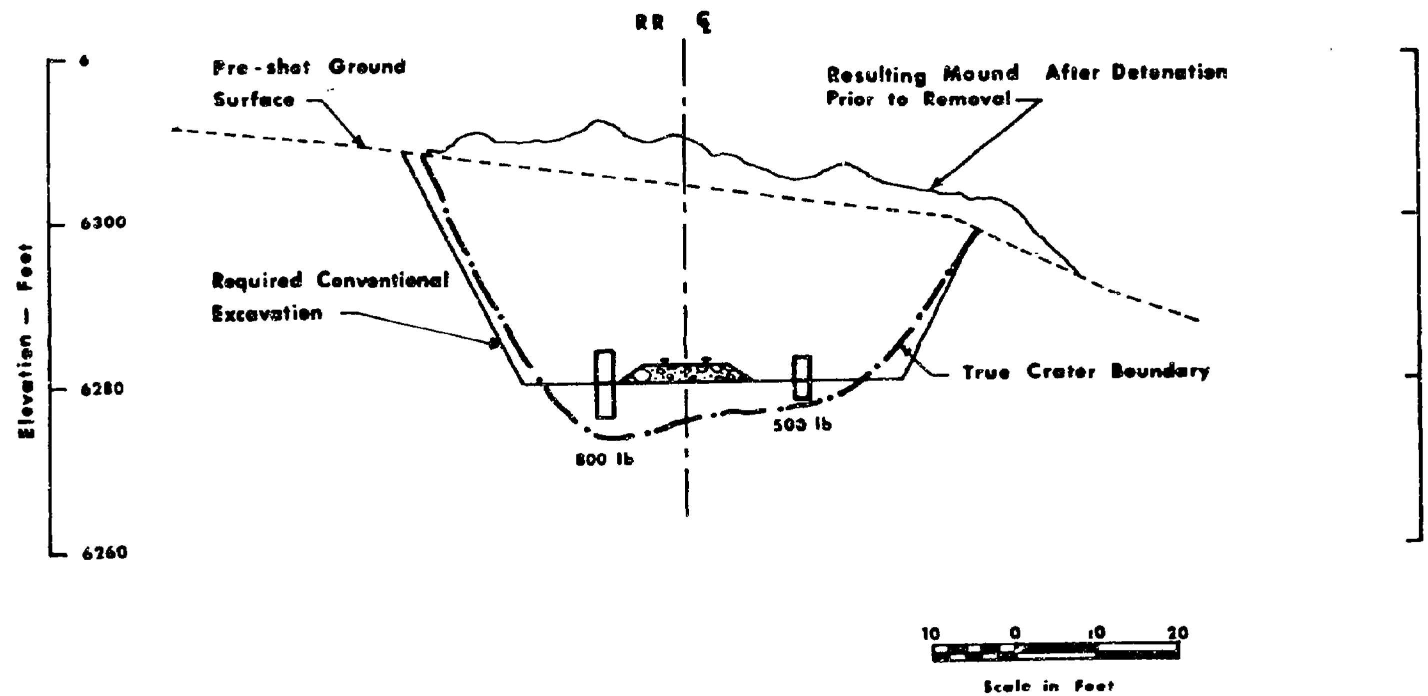


Figure 6. Design for Typical Cross Section of Trinidad Railroad Cut (Mounding)

large concentrated charges are used to fracture and loosen rock material with little or no ejection of material. Conventional equipment will be used to remove the material from the cut to an adjacent fill area. Although similar to conventional blasting in some respects, the use of fewer, although slightly larger, drill holes and larger charges appears to offer economical advantages over a conventional blasting approach.

A second cut 500 feet long and 38 feet deep will be made with a directed cratering concept as depicted in Figure 7. The downhill row of charges will be detonated first lifting the material into the air, followed by detonation of the uphill rows some milliseconds later.

- HIGHWAY CUT - The relocation of Montana State Highway Route 37, as part of the Libby Dam project, is being used to demonstrate the use of explosive excavation to produce sidehill cuts with steep backslopes in a high-strength rock. The design shown in Figure 8 for this 500-foot cut uses charges between cratering size and those of a mounding design. The concept is that the charges will break up the material and cast some of it out of the cut because of the sloping terrain. The material remaining in the cut will be removed by conventional equipment to be used as fill. This will allow any dressing required in the cut and the establishment of the exact grade. To prevent damage to the uphill slope during the cratering process, one or two rows of small drill holes will be loaded and detonated prior to the cratering operations. This technique provides a zone of weakness for the crater boundary to follow during the formation process and prevents upthrust and fracturing beyond this zone. As shown in Figure 8, a conventional row of presplitting holes is also planned to provide the required uphill face.

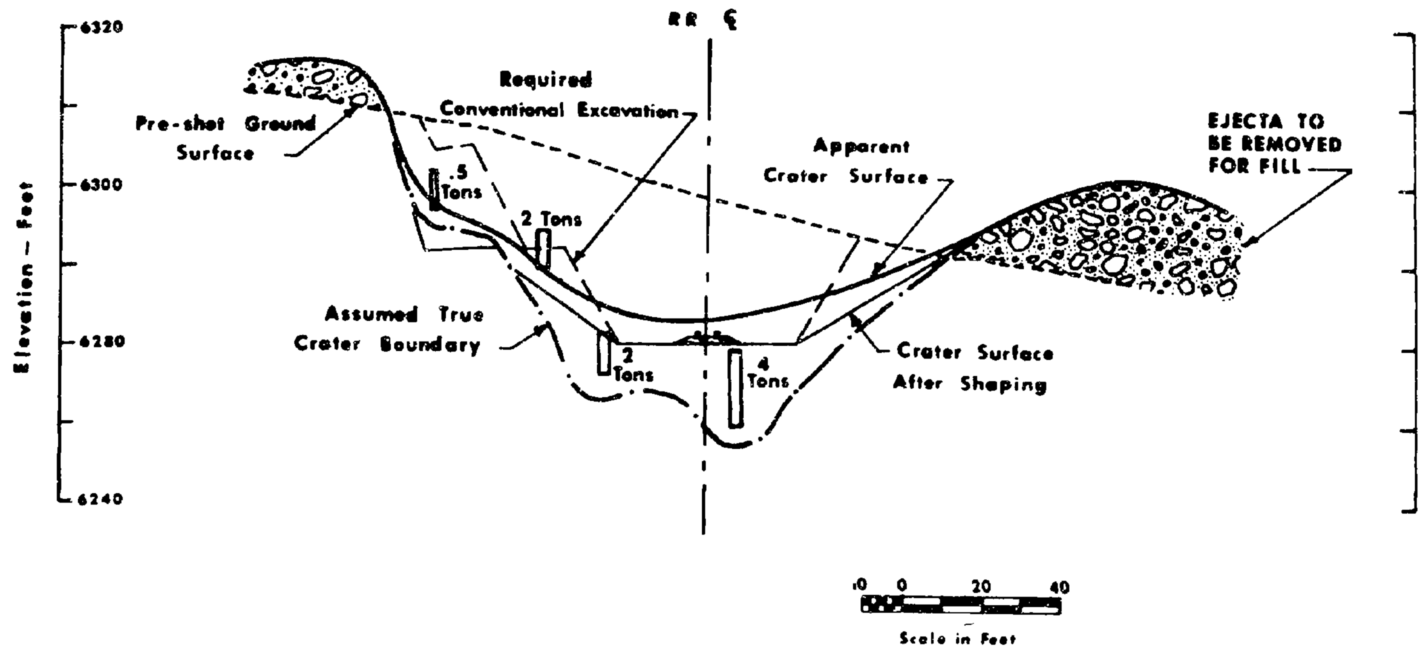


Figure 7. Design for Typical Cross Section of Trinidad Railroad Cut (Cratering)

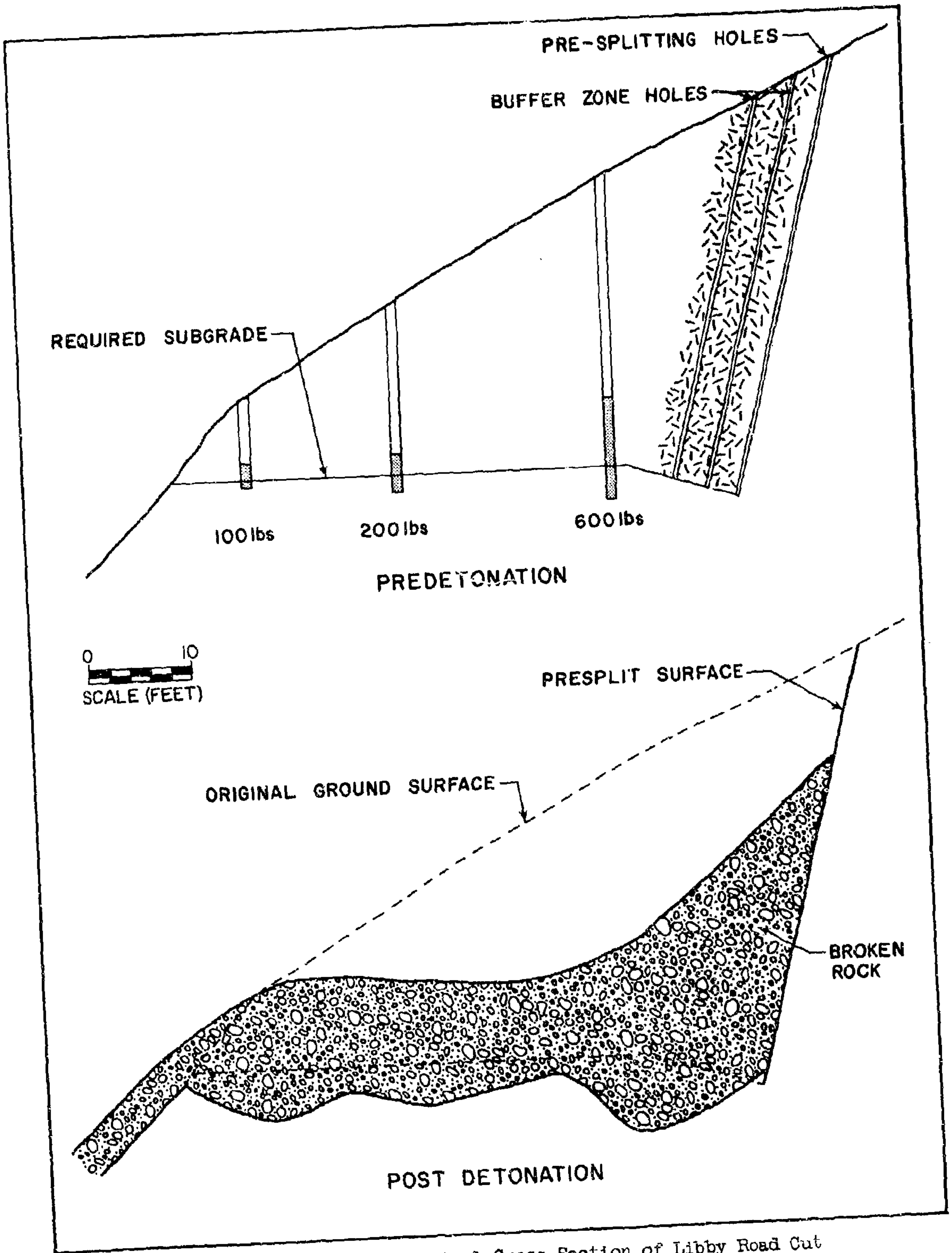


Figure 8. Design for Typical Cross Section of Libby Road Cut

● CHANNEL PLUG - A 375-foot long plug is being blown to complete a dredged channel from Drum Inlet on the coast of North Carolina into the Atlantic Ocean. This excavation will use a double row of 1-ton charges to produce a channel 80 feet wide through a sand bar. This pilot cut will permit the safe operation of a dredge to complete the channel into the ocean.

● UNDERWATER OBSTACLE REMOVAL - Two underwater granitic obstacles, West Francis Rock and Wayanda Ledge, are being considered for removal by explosive excavation to widen the Sergius Narrows Channel of the inland waterway system near Sitka, Alaska. This is an authorized Alaska Engineer District project on which work is planned to start in fiscal year 1972. This is in an area where tidal variations average 12 feet and currents reach 8 knots; therefore, conventional costs are high. The plan calls for the widening of the channel to 450 feet at a minimum depth of 24 feet. For Wayanda Ledge (design plan and cross section shown in Figure 9) this requires the removal of 13,000 cubic yards of rock. The tentative explosive excavation design utilizes a pumpable aluminized ammonium nitrate slurry. The design is based on excavation to 30 feet as a safety factor. The approximate slurry charge sizes vary from 1.5 to 4 tons with sequential detonations between rows from right to left as shown in Figure 10 to cast the material to the right into the deep section of the channel. Approximately the same drilling equipment and platform will be required for either a conventional or explosive excavation approach. However, by using large charges and a directed cratering approach, the explosive excavation method will eliminate the requirement for dredging, and has a consequent overall cost advantage.

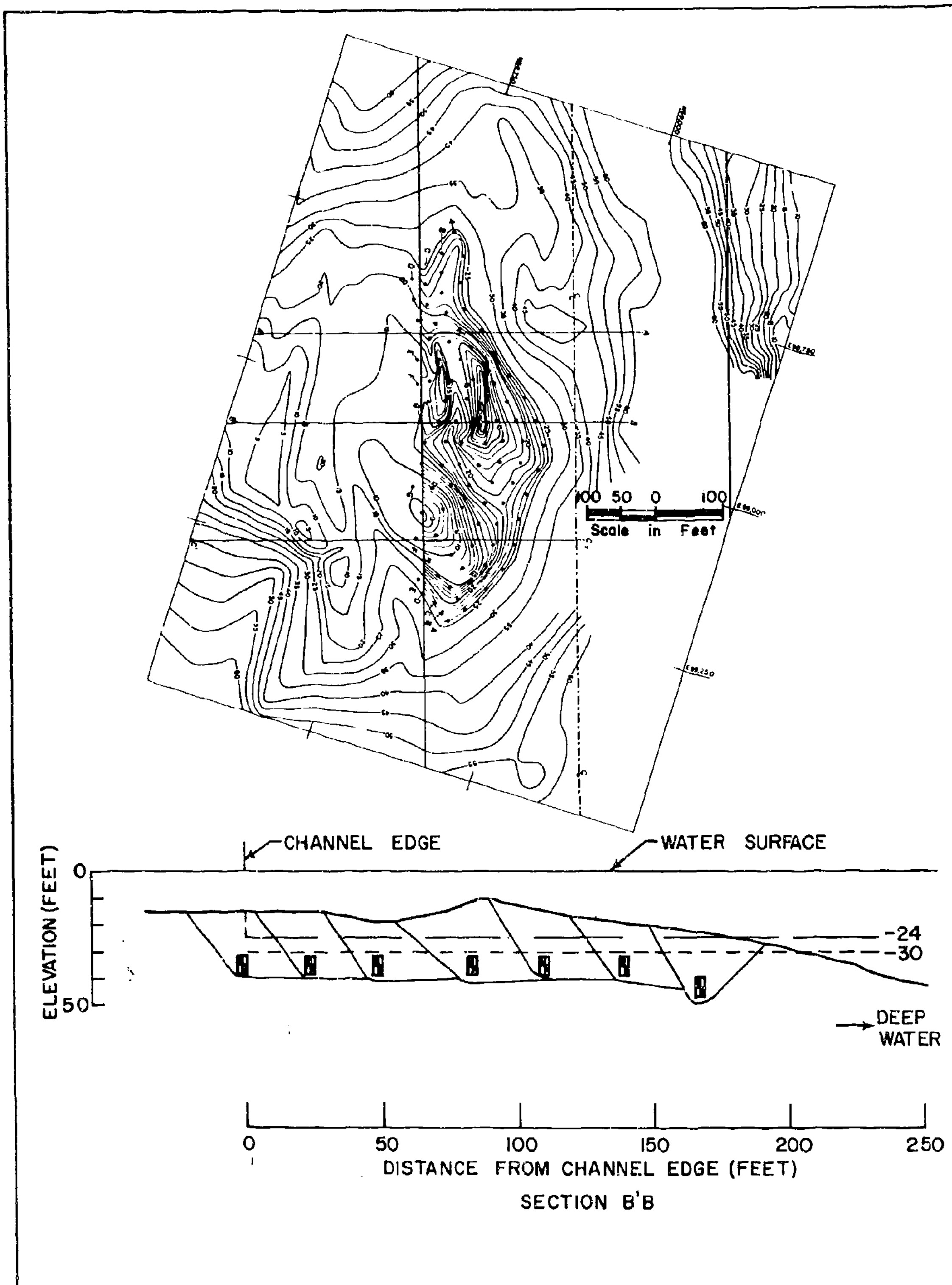


Figure 9. Design for Typical Cross Section of Wayanda Ledge Removal

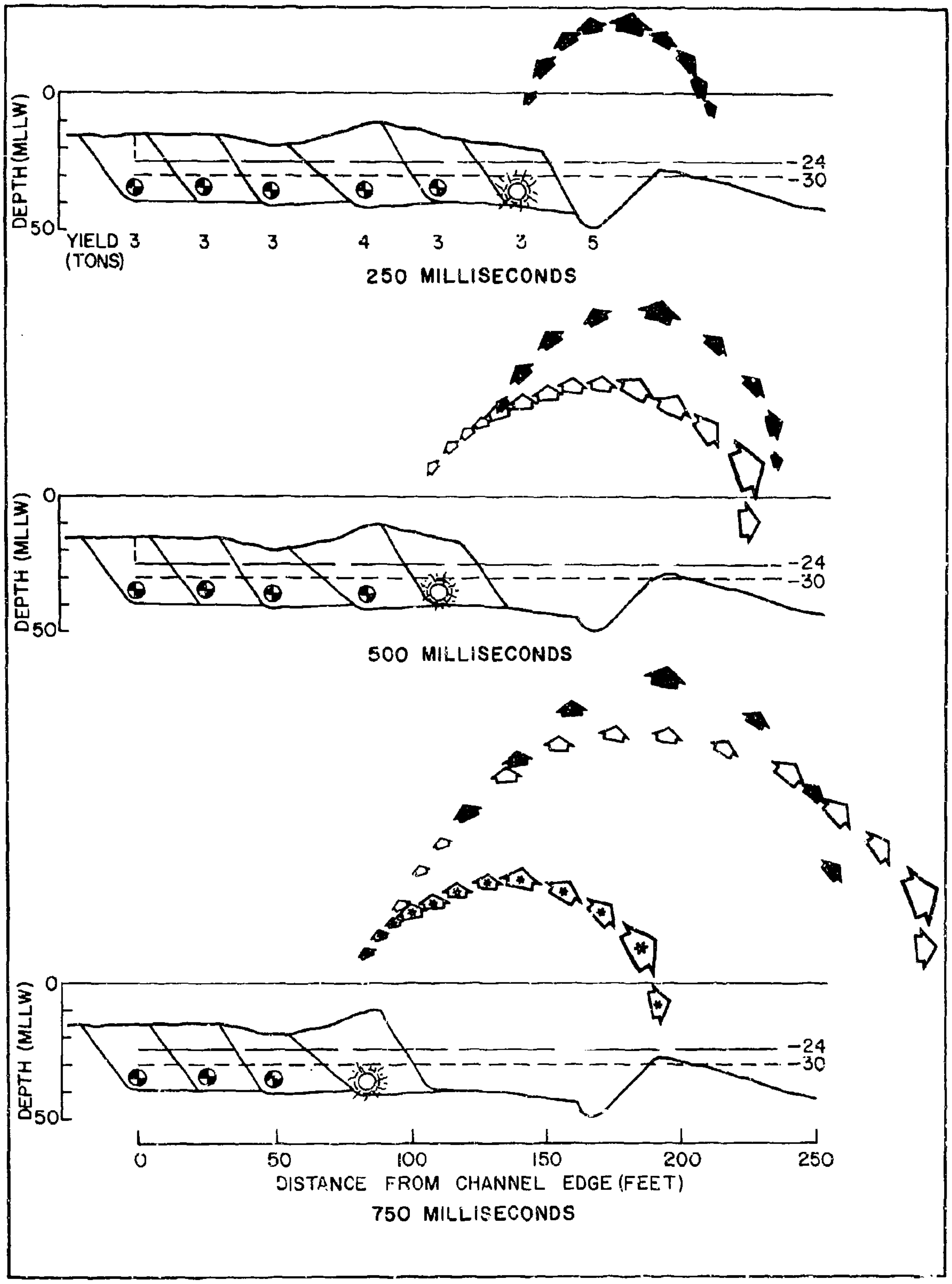


Figure 10. Schematic Detonation of Wayanda Ledge

COST ADVANTAGES

Since the explosive excavation research effort was extended in 1969 to include the development of chemical high-explosive excavation as an accepted cost competitive construction technique, significant progress has been made. As shown on Figure 11, explosive excavation costs have been on a down trend since this time. Actual excavation costs, which were as high as $8.00 to $10.00 per cubic yard during the modeling phase, have been reduced to $1.50 to $2.50 per cubic yard based on the usable cross section, with many additional economies still possible. Conversely, conventional excavation costs continue to rise. The economics of explosive excavation are directly related to the kind of project to which it is applied and the design approach to accomplish the project. Perhaps the greatest economic advantage is obtained when excavating a cut for a water conveyance channel. In this case, the entire explosively excavated cross section can be utilized in calculating the cost per yard. A project requiring only excavation rather than a balanced cut and fill design is desirable. The secondary handling of cratered material in a cut and fill design when the cut is explosively cratered reduces the economics considerably. Possibly the greatest future for the technique is in the area of marine engineering where conventional costs are high and the environmental effects of ejecta, ground shock, and airblast are minimized.

ENVIRONMENTAL CONSIDERATIONS

The environmental factors of ground shock and airblast must always be evaluated when explosive excavation is used. Relatively accurate prediction techniques have now been developed for both these effects, which can be reduced to relatively insignificant levels by sequential detonation of charges and rows. It has been found that a 25-millisecond delay between charges in a row has little effect on crater dimensions but reduces ground shock and airblast to those of the largest single charge within the row.

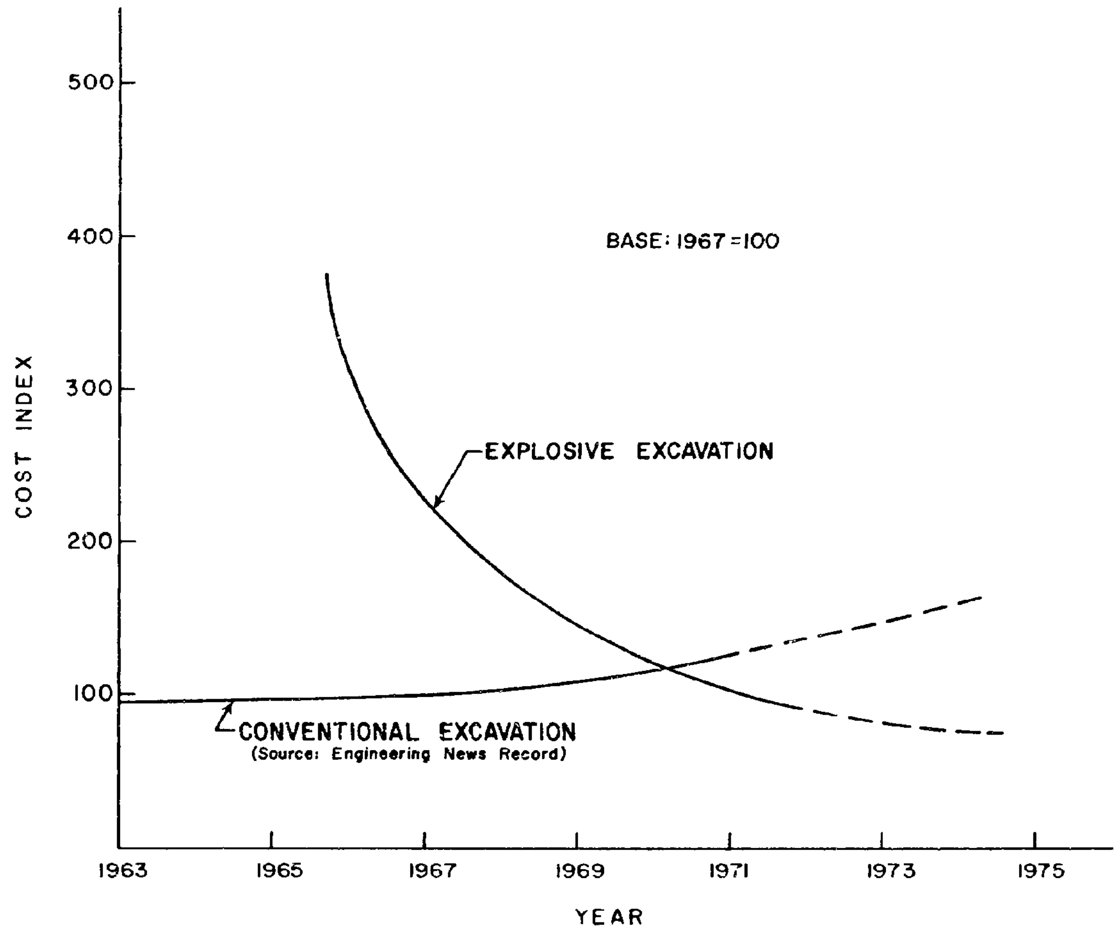


Figure 11. Comparison of Explosive and Conventional Excavation Cost Trends

The mass of the ejecta from a cratering detonation is deposited up to several hundred feet from the cut. On some projects, this throwout could be objectionable. If so, the mounding concept or a compromise between cratering and mounding may be desirable. On a sidehill detonation almost all ejecta is deposited downhill.

Fish kill and ejecta distribution in an underwater detonation were originally considered as limiting factors. However, experience has proven that these effects are not serious. Although ejecta is spread over the marine bottom several hundred feet from a detonation, this disturbance is no greater than that caused by conventional equipment. Fish kill is also limited to several hundred feet from the cratering detonation. On Project TUGBOAT, where 40 tons were detonated at one time, fish kill in prepositioned cages was limited to 300 feet from the shot point.

MILITARY RESEARCH

A comparable program to that just discussed for Civil Works projects is being conducted for military uses of explosive excavation. The use of large chemical charges is being investigated for both military construction and combat operations as well as to demonstrate in simulated form various atomic demolition munition applications. The data from the civil and military programs is integrated into the overall development of explosive excavation technology.

SUMMARY

The explosive excavation pproach to construction projects has been demonstrated on a water conveyance channel, a harbor and a railroad cut. Projects presently in progress include additional railroad cuts, a highway cut, a channel excavation, a channel widening project and several military applications.

Since the principal objective of the Corps is to develop explosive excavation as an accepted cost-competitive construction technique, future research and work will emphasize simplification and refinement of design and execution procedures. To accomplish this objective, the information must be made available to engineers in the field. To this end, a comprehensive report entitled "Explosive Excavation Technology,"NCG TR-21, was recently published, including general guide specifications.

Large reductions in emplacement and explosives costs have been experienced in the past two years in the process of developing explosive excavation, and further significant reductions appear feasible. These reductions, when combined with more efficient designs and execution techniques, should continue the downward cost trend of explosive excavation as shown in Figure 11. When this reducing cost trend is compared with the rising cost trend of conventional construction, the promise of significant savings in both time and money is evident for many future excavation projects.

LARGE YIELD EXPLOSIVE CHARGES AND EFFECTS*

Walter C. Day

Introduction

This paper summarizes the experience of the U. S. Army Engineer Explosive Excavation Research Office (EERO), an activity of the Waterways Experiment Station, and its predecessor the Nuclear Cratering Group (NCG) in designing and detonating relatively large chemical explosive charges underground at cratering and mounding depths. Because it would be impossible to present all data acquired, the paper will focus on the two topics "explosives" and "effects". Data will be presented in summary fashion using curves and tables designed for making predictions for similar detonations. Information specific to a given test will be presented only where it is of special interest. As would be expected, the curves and tables are based on all pertinent data available in the literature in addition to that resulting from EERO sponsored tests.

Summary of EERO (NCG) Tests

EERO experience dates back to the Pre-Buggy experiments at the Nevada Test Site in 1962 and is currently continuing with two military test series and four civil program application tests this fiscal year. The list of projects since Pre-Buggy include the Pre-Schooner tests, the Pre-Gondola tests, Project TUGBOAT, and Project TRINIDAD. A summary of basic information on these tests through the first part of Project TRINIDAD is presented in Tables 1 and 2. Table 1 contains single charge

---

*Much of the material presented in this paper is taken directly from a recent publication of EERO titled "Explosive Excavation Technology", NCG TR-21 (see reference 1).

Table 1. Major Single Charge Cratering Experiments [a, e]

Series name	Shot designation	Sponsor	Date	Medium	Type explos	Charge weight (lb)	Charge burial depth (ft)	Apparent crater radius (ft)	Apparent crater depth (ft)	Apparent crater volume (ft^3)
Pre-Buggy I	Test	NCG		Alluvium (NTS Area 5)	Nitro-methane	1,017	15.0	22.7	10.9	Not reported
	1		12/5/62			1,003	15.0	21.0	9.7	6,560
	2		12/10/62			1,011	16.6	21.8	9.1	7,560
	3		12/11/62			1,011	18.2	20.9	7.8	5,830
	4		12/13/62			1,009	19.8	20.6	9.4	6,530
	5		12/18/62			1,016	21.4	19.7	4.1	2,650
	6		12/19/62			1,015	19.6	20.7	8.3	6,080
Pre-Buggy II	F1	NCG	8/6/63	Alluvium (NTS Area 5)	Nitro-methane	1,000	19.8	22.7	11.8	7,860
	F2		8/6/63		Nitro-methane	1,000	19.8	21.2	11.8	6,030
	F3		8/6/63		TNT	950	18.5	21.1	11.0	6,950
	F4		8/6/63		TNT	950	18.33	22.1	10.8	7,560
Pre-Schooner I	Alfa	NCG	2/6/64	Basalt (NTS)	Nitro-methane	39,250	58.0	50.3	22.9	75,800
	Bravo		2/13/64			39,450	50.2	49	25.5	73,900
	Charlie		2/25/64			39,840	66.1	Mound	-1.3	Mound
	Delta		2/27/64			39,590	41.8	46.1	25.6	64,800
Pre-Schooner II		NCG	9/30/65	Rhyolite (Idaho)	Nitro-methane	171,000	71.1	95.2	60.7	669,000
Pre-Gondola I	Bravo	NCG	10/25/66	Bearpaw clay shale (Montana)	Nitro-methane	39,240	42.49	80.4	32.6	277,550
	Charlie		10/28/66			38,720	46.25	78.5	29.5	241,260
	Alfa		11/1/66			40,700	52.71	76.1	32.1	235,300
	Delta		11/4/66			40,480	56.87	65.1	25.2	133,880
	SC-4		6/21/66			1,000	12.2	24.5	13.0	
	SC-2		6/22/66			1,000	15.8	27.3	12.5	
	SC-1		6/20/66			1,000	19.1	7.1	2.8	
	SC-3		6/23/66			1,000	23.3	14.6	3.4	
Pre-Gondola III Phase I	A	NCG	7/25/68	Bearpaw clay shale (Montana)	Nitro-methane	2,000	6	21.5	11.5	
	B					2,000	12	25	13	
	C					2,000	14.3	27.2	14	
	D					2,000	16.8	25.8	12	
	E					2,000	19.5	27	11.7	Not reported
	F					2,000	22	25.4	11	
	G					2,000	24	18	6.4	
	H					2,000	26	0	0	
Tugboat Phase I	Alfa	NCG	11/6/69	Coral and water (Hawaii)	Aluminized ammonium nitrate slurry	2,000	16.33	56.2[b]	10[c]	
	Bravo		11/6/69			2,000	16.66	52.2[b]	11[c]	
	Charlie		11/4/69			1,975	20.12	68.0[b]	10[c]	
	Delta		11/5/69			1,950	24.74	53.2[b]	11[c]	
	Echo		11/7/69			20,200	41.3	129.0[b]	15[c]	

Series name	Shot designation	Sponsor	Date	Medium	Type of explosive	Charge weight (lb)	Charge burial depth (ft)	Apparent crater radius (ft)	Apparent crater depth (ft)	Apparent crater volume (ft^3)
Trinidad[d]	B1	NCG	8/13/70	Interbedded sandstone and shales	ANFO	3,000	15.2	17	8.0	3,200
	B2		8/14/70			2,000	18.0	20	11.5	6,000
	B3		8/12/70			2,000	19.7	24	6.5	3,500
	B4		8/13/70		Aluminized (18-20%) ammonium nitrate slurry	2,000	15.9	23.5	12.8	9,100
	B5		8/11/70			2,000	18.6	23.2	13.0	8,100
	B6		8/10/70			2,000	20.9	21.5	11.5	7,000
	B7		8/12/70			2,000	22.6	20.2	6.0	3,500
	B8		8/11/70			2,000	28.1	Mound		

[a]Portions of this table were taken from reference 2.

[b]Radius at preshot coral surface.

[c]Depth below Mean Lower Low Water Level (MLLW).

[d]All data are preliminary.

[e]Trinidad Military Series (Middle Course I) does not appear in this table.

Table 2. Major Multiple Charge Cratering Experiments [a, b]

Series name	Shot designation	Sponsor	Date	Medium	Type of explosive	Charge weight (lb)	Charge burial depth (ft)	Spacing between charges (ft)	Average apparent crater width (ft)	Average apparent crater depth (ft)	Apparent crater volume (ft^3)	Apparent crater volume per lb of explosive (ft^3/lb)
Pre-Buggy I	A	NCG	1/16/63	Alluvium (NTS Area 5)	Nitromethane	5 ea 1,016	10.8	20.6	44.5	12.1	35,100	6.91
	B		1/23/63			5 ea 1,023	19.8	30.9	33.1	4.9	12,960	2.53
	C		1/31/63			5 ea 1,007	19.8	25.8	38.6	4.4	17,820	3.54
	D		2/7/63			5 ea 1,004	19.8	23.2	42.8	6.4	24,435	4.87
Pre-Gondola II		NCG	6/28/67	Bearpaw clay shale (Montana)	Nitromethane	274,820					1,312,631	4.78
						Charlie Crater[c]		105.5				
						E77,200	59.7		206.5	55.5	Volumes by section not reported	
								79.8				
				Width and depth averaged from midpoint to midpoint between charges		F39,400	49.4		152.5	37.5		
								79.9				
						G39,100	48.8		164.0	36.9		
								79.0				
						H79,120	59.9		214.5	57.0		
								79.9				
						I40,000	48.8		173.0	33.5		
Pre-Gondola III Phase I		NCG	9/68	Bearpaw clay shale (Montana)	Nitromethane	7 ea row 2,000 (2 rows)[d]	19.0	27.0	64.2	14.6	Not reported	
Pre-Gondola III Phase II		NCG	10/30/68	Bearpaw clay shale (Montana)	Nitromethane	300,500					2,350,000	5.57
						Charge I[e]		93.3				
						M60,000	5.6		196	54	Volumes by section not reported	
								86.0	190	55		
						N58,800	0.50		185	46		
								86.6	191	49		
						O60,200	55		182	53		
				Width and depth measured at charges and midpoints				86.0	187	47		
						P60,500	52		182	46		
								87.1	199	49		
						Q61,000	51		212	50		
								52.6	223	52		
						R60,600	50		202	57		
								52.1	217	52		
						S60,500	54		216	46		
Pre-Gondola III Phase III enhancement experiments	Row	NCG		Bearpaw clay shale (Montana)	Nitromethane							
	A-1		8/14/69			6 ea 2,000	10.3	27	64	15.0	Not reported	7.8[f]
	A-2		10/24/69			7 ea 2,000	21.0	23	68	17.5		8.5[f]
	A-3		10/24/69			5 ea 2,000	17.0	31	60	15.5		8.2[f]
	B-1		8/14/69			7 ea 2,000	23.0	19	76	17.5		7.7[f]
	B-2		10/27/69			6 ea 2,000	21.0	23	70	16.5		7.9[f]
	B-3		10/27/69			9 ea 2,000	26.0	15	86	22.0		8.7[f]

Series name	Shot designation	Sponsor	Date	Medium	Type of explosive	Charge weight (lb)	Charge burial depth (ft)	Spacing between charges (ft)	Average apparent crater width (ft)	Average apparent crater depth (ft)	Apparent crater volume (ft^3)	Apparent crater volume per lb of explosive (ft^3/lb)
Pre-Gondola III Phase III reservoir connection	Charge	NCG	10/6/69	Bearpaw clay shale (Montana)	Aluminized ammonium nitrate slurry	5 chgs 30,000	37.0		240	52	550,000	3.9
								60				
						70,000	52.0		225	66		
								65			Volumes by section not reported	
						20,000	37.0		165	44		
								55				
						10,000	30.0		124	37		
								50				
						10,000	25.0		110	38		
Tugboat Phase II	Outer channel row	NCG	4/23/70	Coral and water (Hawaii)	Aluminized ammonium nitrate slurry	4 chgs 20,000 each	42	100	163[g]	21[h]	2,173,100	—
	Inner channel row		4/28/70			4 chgs 20,000 each	42	120	206[g]	13.8[h]		—
	Square array		5/1/70			4 chgs 20,000 each	42	120	Square avg[g] 309 by 290	14.7[h]	1,545,500	19.3
Trinidad[i]	C1	NCG	9/28/70	Inter-bedded sandstones and shales	Aluminized (18-20%) ammonium nitrate slurry	5 chgs 2,000 each	18	32	48	12.8		5.8
	C2		9/29/70			5 chgs 2,000 each	20	25	51	14.1		4.7
	C3		10/1/70			7 chgs 2,000 each	23	18	67.4	18.9		6.2
	C4		10/1/70			5 chgs 2,000 each	20.6	25	50.8	10.8		4.3
	C5		10/2/70			5 chgs 2,000 each 2 parallel rows	20.2	25	53	12.8		4.8
	C6		9/30/70			5 chgs/row 2,000 each	20	25	Not reported	Not reported		4.8
	D1	NCG	11/17/70	Interbedded sandstones and shales	ANFO	9 chgs 200 to 2,000	13 to 24	$0.8R_a$		Max 20		5.6
	D2		11/18/70		5% Al-AN	5 chgs 2,000	18	$1.6R_a$		Max 10		4.0
	D3		11/19/70		35% Al-AN	12 chgs 2,000 and 4,000	10 and 25	1.4 and $1.1R_a$		Max 15		3.0 (avg) 5.3 (max)
	D1		12/16/70		20% Al-AN (two parallel rows)	32 chgs 2,000 and 4,000	17 to 25	0.9 to $1.25R_a$				5.5

[a]Portions of this table were taken from reference 2.

[b]Multiple charge in this case includes single row charge layout, double row charge layout, a triple row layout, and a square array of four charges.

[c]Already existing from Pre-Gondola I Series.

[d]This was a 3-row-charge experiment; the two outside rows were fired simultaneously, then the center row was fired to remove the mound between the two rows and to produce a broad flat crater. Only average dimensions for the craters produced by the two outside rows are included here.

[e]Nearest charge location in Pre-Gondola II row.

[f]These factors are derived for the linear section of the crater only, excluding ends.

[g]At 12-ft depth contour.

[h]Depth below Mean Lower Water Level (MLLW).

[i]All data are preliminary.

test data and Table 2 contains multiple charge test data. These two tables contain only the larger tests (1000 lbs or more per charge). Many smaller scale field tests and 1 to 8 lb model scale tests have been conducted.

Because of EERO's primary interest in civil works and military construction and the use of nuclear and chemical explosives in Military Tactical Destruction and Denial Operations the depths of burst for the majority of tests range around a depth which results in optimum crater size. This paper deals primarily with data having application in construction applications.

The early experiments conducted by EERO (NCG) were directly related to the AEC Plowshare Program. Each experiment was designed to achieve one or several specific objectives not always related to explosive excavation. Several of the larger experiments were specifically aimed at calibrating a geologic medium or specific site for possible future nuclear experiments, or in modeling a planned nuclear cratering experiment in some way. Emplacement construction and explosive selection were always done to satisfy criteria other than that which would apply to a construction application. Fortunately, some of the experiments were conducted solely to gather data on explosion-generated effects, especially related to safety. Beginning with the last phase of the Pre-Gondola tests in the fall of 1969 the emphasis changed from one of calibrating and modeling for nuclear experiments to one of cost reduction in the use of large chemical explosive charges in construction. This drastically changed emplacement construction and explosive selection criteria as will be shown later. The current effort remains in the cost reduction area and significant gains are being made.

As can be seen in Tables 1 and 2, cratering experience has been gained in alluvium, basalt, rhyolite, clay shale, coral and water, and interbedded sandstone and shale.

Explosives

Two primary charge shapes have been used in the experiments listed in Tables 1 and 2. During the early experiments the charges were spherical in shape to model as closely as possible a nuclear gas cavity immediately following detonation. A few of the small Pre-Buggy shots used cast TNT in these spherical shapes. However, because of the convenience of filling a spherical container through a small fill line with a liquid explosive after emplacement construction was completed, nitromethane was chosen as the best explosive to use. A typical charge design for the larger detonations is shown in Figure 1. The cavity had to be mined and brought to tolerance with shotcrete and an impermeable sealer applied that would contain the low viscosity nitromethane. Elaborate precautions were taken to provide adequate stemming to prevent premature venting of the cavity gasses. Two techniques used were to provide a key in the stem and to use grout that matched the medium as closely as possible, specifically in its shear strength. Booster designs have varied. In a few cases the booster charge was put in place prior to stemming. Later a system was devised to lower a booster down an access pipe after the charge cavity had been stemmed and filled with nitromethane. Booster systems used with the nitromethane have employed electric caps, exploding bridge wire and a high explosive booster charge of Composition C-4 or similar high explosive. More recently, primacord has been used as a link between the primary initiator and the HE booster charge.

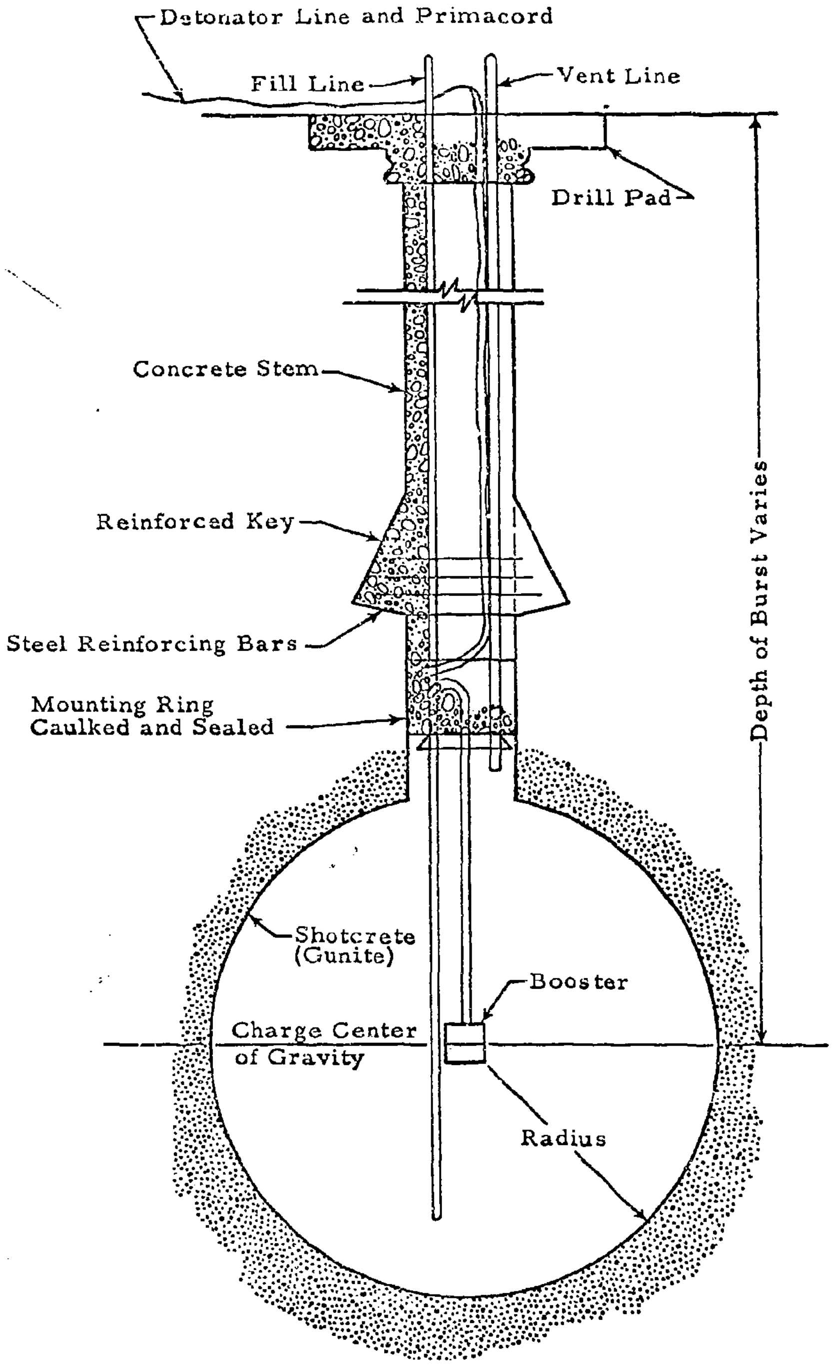
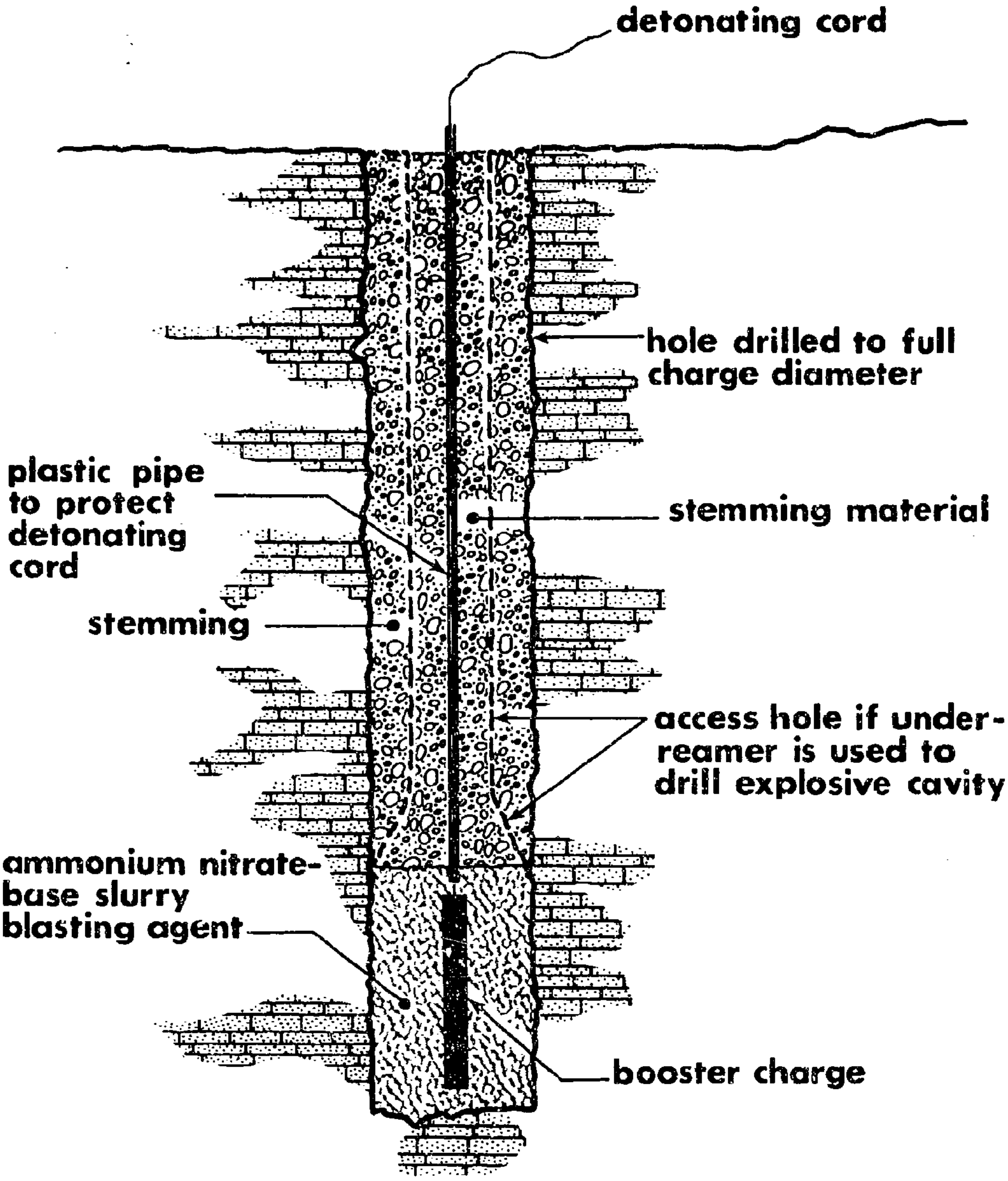


Figure 1. Centerline Section of Typical Charge Emplacement for Nitromethane

With the change in research emphasis to cost reduction mentioned earlier, cylindrical charge shapes as shown in Figure 2 have been used. The emplacement hole must be drilled in most cases and a cylindrical charge shape allows the direct use of large diameter drilling equipment or smaller diameter equipment with an underreaming capability. Explosive selection drifted to the cheaper ammonium nitrate based blasting agents and explosives, specifically ANFO and the aluminized ammonium nitrate slurries. In some cases jelled explosives were used to inhibit leakage and make stemming easier. Pit run gravel or native material was used for stemming without any elaborate designs. Charge length to diameter ratios of up to 3 to 1 have been used without significant change in crater dimensions.

Because of misfire problems experienced during Project TUGBOAT the use of full or 3/4 column length HE boosters have been specified for the cylindrical charge shape when using ANFO or aluminized ammonium nitrate slurries. In that project, ten ton cylindrical charges were placed in a coral and sea water environment. The explosive was a jelled aluminized ammonium nitrate slurry. A commercial one pound booster normally used in the mining industry for this purpose was used. Four of these 1 lb. booster charges were strung on primacord at fifth points down the center of the charge. This design resulted in only partial high order detonation of some of the charges. A revised design using a full column booster resulted in complete high order detonation of the charge.

EERO experience has resulted in several conclusions regarding explosive selection for excavation. The selection will involve a number of compromises. A trade off must be made between the maximum excavated volume per pound of explosive and the cost. Drilling costs, transportation,



Typical Charge Emplacement

sto·.ge, and labor costs at an application site also must be considered. However, some specific guidelines can be recommended.

(1) Total heat of detonation and especially gas bubble energy should be as high as possible. Unfortunately, high energy explosives are expensive and a compromise must be reached between explosive cost and emplacement cost. A high ratio of heat of detonation to explosive cost is always advantageous. Typical values of such ratios, using nominal market prices as of this writing, are presented for several explosives in Table 3.

(2) As a rule of thumb, the best cratering performance can be expected when the explosive-to-rock-impedance ratio, I_e/I_m, is between 0.2 and 1.0, and the closer to 1.0 the better. For this calculation, I_e may be taken as the product of the explosive bulk specific gravity and the characteristic detonation velocity; similarly, I_m may be taken as the product of the media bulk specific gravity and its characteristic seismic velocity. In some media, for example soil and clay shale, the impedance ratio usually exceeds unity regardless of the explosive. Under such circumstances a low impedance explosive, such as ANFO, can be selected although impedance matching is not as important in common excavation as in rock excavation.

Detonation impedances for some explosives are given in Table 3, and acoustic impedances of some materials are given in Table 4.

(3) An upper limit to detonation pressure is desirable because an explosive with an excessively high detonation pressure will dissipate considerable energy in excessive crushing and plastic deformation near the charge. There is no clear indication as to what this upper limit should be but experience has shown that explosives with detonation pressures exceeding 150 to 200 kbar tend to perform poorly as cratering explosives.

Table 3

Measured Properties and Calculated Parameters of Representative Cratering Explosives

Explosive	Detonation pressure (kbar)	Bulk specific gravity	Detonation velocity (m/sec)	Impedance (m/sec)	Heat of detonation (cal/g)	Nominal cost ($/lb)	Energy/cost (Mcal/$)	Excavated volume relative to equal weight of TNT[a]
ANFO	60	0.93	4560	4240	890	0.06 ± 0.04	6.75	1.0-1.1
AN slurry	104	1.40	6050	8470	730	0.15 ± 0.05	2.22	1.0-1.2
AN slurry (2% Al)[b]	60	1.30	4300	5590	750	0.08 ± 0.05	3.41	1.0-1.2
AN slurry (8% Al)[b]	66	1.33	4500	5990	1110	0.13 ± 0.05	2.52	1.2-1.4
AN slurry (20% Al)[b]	85	1.20	5700	6840	1450	0.20 ± 0.07	2.19	1.5-1.7
AN slurry (35% Al)[b]	81	1.50	5000	7500	1950	0.25 ± 0.10	2.52	1.6-1.8
TNT	220	1.64	6930	11360	1102	0.25 ± 0.05	2.00	1.00
Nitromethane	125	1.13	6320	7140	1126	0.33 ± 0.02	1.55	1.0-1.3
Composition C-4	257	1.59	8040	12780	1350	0.34 ± 0.10	1.80	1.2-1.4

[a]That is, "Cratering Effectiveness" as measured by small charge detonations in sand. Absolute cratering performance in terms of volume excavated per pound of explosive depends on the size of the shot; it is less for larger shots. Relative performance, on the other hand, is not as sensitive to charge size.

[b]Slurry blasting agent.

Table 4. Acoustic Impedance of Some Materials (references 3 & 4)

Media	Nominal bulk specific gravity	Nominal seismic velocity (m/sec)	Acoustic impedance, I_m (m/sec)
Alluvium	1.54	1000	1540
Basalt	2.59	5400	13990
Clay shale	2.06	2000	4120
Granite	2.65	5100	13510
Limestone	2.66	5200	13830
Sandstone	2.40	2400	5760
Water	1.00	1460	1460

There are also some operational considerations that affect explosive selection. A practical cratering explosive must be capable of being shipped to the site with comparative ease, stored without hazard for several months, and placed down-hole with efficiency. Also, fumes given off by the detonation must not be so toxic as to require evacuation of personnel. Five characteristics govern whether the above needs will be met: (1) the explosive density, (2) its water resistance, (3) its classification in the Code of Federal Regulations (CFR), (4) its viscosity or pourability, and (5) its composition.

Density and water resistance are important if there is a likelihood of water in the borehole due to seepage or runoff. The explosive must then be dense enough to displace water and sufficiently water-resistant to detonate when wet. A specific gravity of 1.1 or more is preferable under such circumstances. Nearly all high explosives, ammonium nitrate slurries, and gelatin dynamites are sufficiently water-resistant for application in flooded boreholes. ANFO and other dry ammonium nitrate mixes, such as ammonol, are not.

When water is not present, explosive density is important only from the standpoint of emplacement cost (assuming, of course, the impedance preferences discussed earlier have been satisfied); i.e., a denser explosive of comparable performance will be cheaper to emplace because the charge cavity is smaller.

Shipping costs are directly related to the CFR classification. Cratering explosives classified as oxidizing materials are reasonably inexpensive to ship. Class A explosives in large quantities are very expensive to transport and therefore should be avoided. Class C explosives are usually no more expensive to ship than oxidizers but there

are restrictions as to the size of the shipment. Nitromethane, although it can be used as a powerful explosive, has no explosive classification and is shipped as an industrial solvent.

It should be possible to pump or pour an ideal cratering explosive into the charge cavity without leakage into underground fissures and cracks. Upper and lower limits on the viscosity of the mixture are required unless the explosive is to be placed in sealed containers--an added expense. To accommodate these requirements, gelling agents are often added to slurries as they are being pumped down-hole. The mixture then sets up as a rubbery or putty-like solid. To minimize leakage, down-hole viscosity should be high. Some dry mixes such as prilled ANFO and pelletol (pelletized TNT) usually pose no pumping or seepage problem. Nitromethane, on the other hand, has a viscosity about equal to that of warm water and consequently must always be emplaced in sealed cavities or leak-proof containers.

Toxic fumes are minimized when the explosive is properly oxygen-balanced. An excess of oxygen in an explosive, such as might arise from the exposure of AN to water or high humidity, can produce brown nitrogen dioxide upon detonation and, under some circumstances, during storage. An oxygen deficiency such as occurs in TNT, pelletol, and tritonal may, depending on density, yield colorless but toxic carbon monoxide. Generally, if oxygen imbalance is held within 4% by weight, toxic fume production will be negligible. Stability during storage is also improved if the above criterion is met. Most nitrate-based explosives, such as amatol, ANFO, and most slurries, are adequately oxygen-balanced so that toxic fume production is minimized.

Effects

The major effect of interest from an underground detonation is the size of the crater produced. There are also other potentially hazardous effects to people, structures and the general environment around a detonation site. These include ground motion, airblast, underwater shock, water waves and missiles. Current prediction data will be summarized for each in turn.

Because of length limitations, these effects predictions will be limited to single charge detonations. Many techniques have been developed for extending the prediction capability to multiple charge detonations and the reader is referred to reference 1 for a description of these.

To avoid complications in scaling crater dimensions the crater dimensions presented here are for TNT as the cratering explosive. Other types of explosives give different crater dimensions. If it is assumed that TNT has a cratering effectiveness of 1, based on the volume of material excavated at optimum depth of burial, then the other explosives can be related to this by determining the volume excavated at optimum depth of burial for each one. This has been done for the explosives listed in Table 3 in a sand medium. The results are listed in the last column of Table 3. These values have not been specifically tested in all media at a range of yields and are expected to vary some but not significantly.

Similarly, the remaining effects data given also assume the use of TNT as the cratering explosive. Where effects data for other explosives are desired an "energy equivalent" yield should be used. The term "energy equivalence" is taken to mean simply the ratio of heat of detonation of a given explosive. Heats of detonation of the explosive discussed in this paper are given in Table 3. The energy equivalence of an explo-

sive (A) in terms of tons of TNT can be found from the formula

$$\text{Tons TNT} = (\text{Tons explosive A})\left(\frac{Q_A}{Q_{TNT}}\right),$$

where Q is the heat of detonation in calories per gram.

Crater dimensions. Crater dimension curves scaled to one ton TNT which best represent the availabe chemical explosive cratering data are presented in Figures 3, 4 and 5. The curves for crater radius and depth are based on data from experiments involving charge weights from 0.25 to 500 tons, with charge weights from 0.5 to 20 tons being most common.

The cratering curves for dry rock are based primarily on data from experiments in basalt, a high strength rock, with some verification from experiments in rhyolite. The curves for dry soil apply to desert alluvium, loess, dry sand, and materials of similar physical properties. They also apply to certain low strength sandstones. The curves for saturated clay shale are also reasonably valid for saturated sand. The crater curves for dry rock and saturated clay shale may be regarded as the lower and upper limits, respectively, for crater dimensions in materials not mentioned above.

For maximum efficiency, a cratering charge is ordinarily buried at a depth which will assure the greatest apparent crater volume. In the three materials considered here the optimum depths of burial and the resulting crater dimensions which result in maximum volume are listed in Table 5 for the range of typical charge sizes. The burial depths and dimensions for the 10- and 50-ton charges are simply those for the 1-ton charge multiplied by $10^{0.3}$ and $50^{0.3}$, respectively.

Although the apparent crater radius and depth are the first criteria for explosive excavation design, parameters which describe the crater lip,

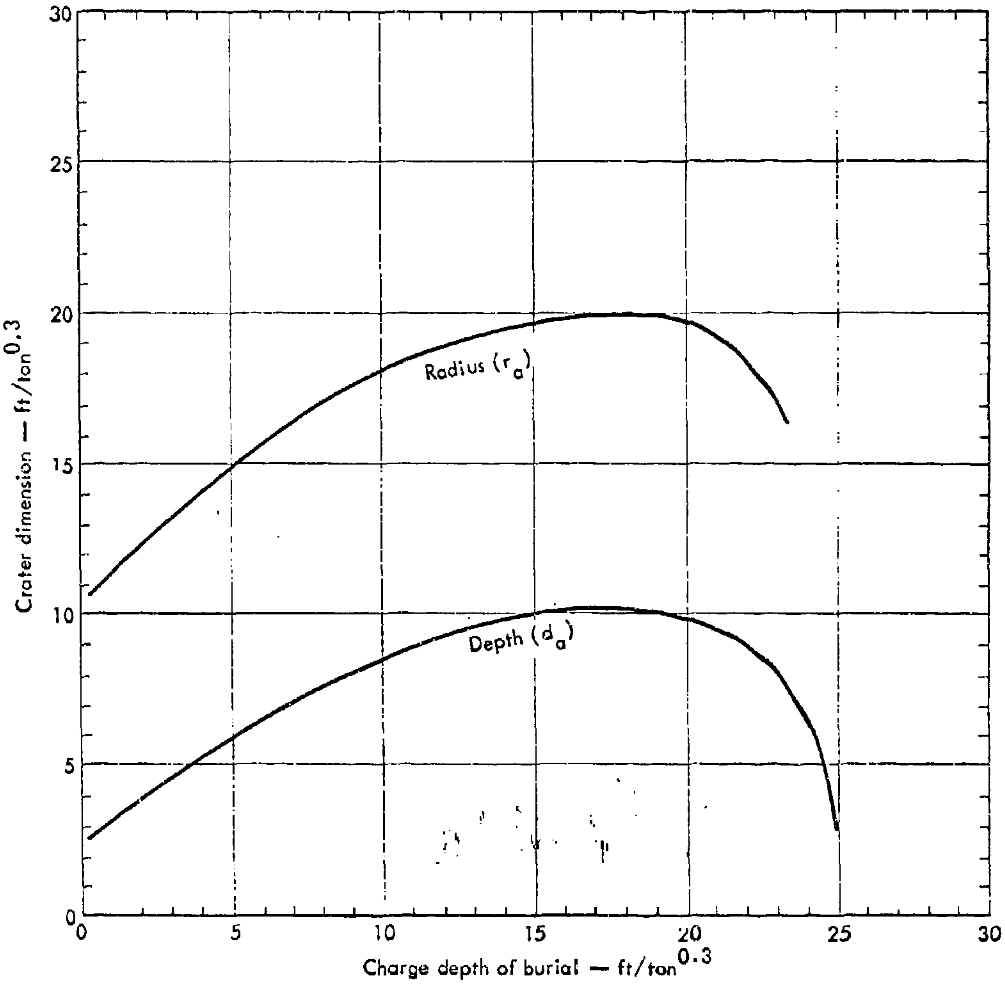


Figure 3. Crater Dimensions Scaled to 1-ton Charges of TNT or Equivalent Buried in Dry Rock

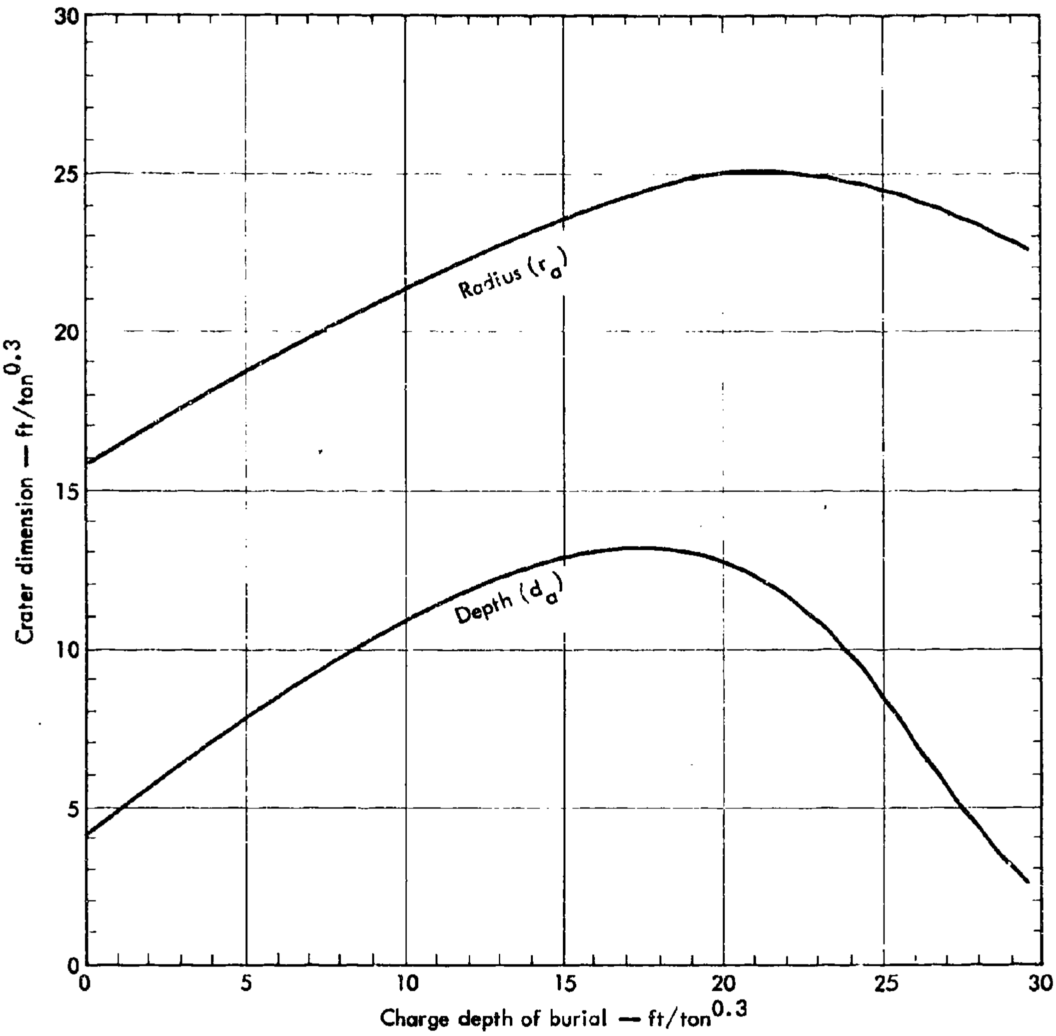


Figure 4. Crater Dimensions Scaled to 1-ton Charges of TNT or Equivalent Buried in Dry Soil

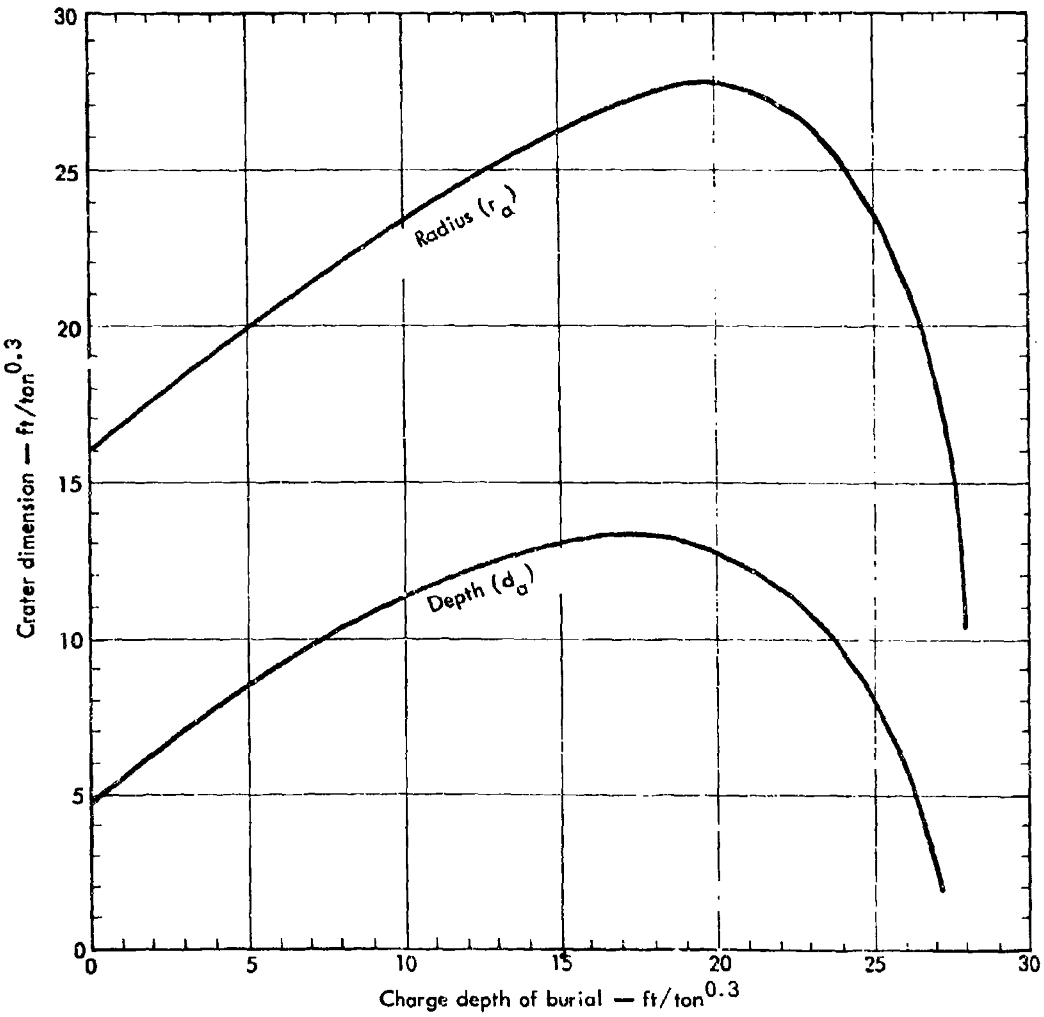


Figure 5. Crater Dimensions Scaled to 1-ton Charges of TNT or Equivalent Buried in Saturated Clay Shale

Table 5

Single-charge Crater Parameters for Optimum Depth of Burial

Material	Charge size (tons)								
	1	10	50	1	10	50	1	10	50
	Depth of burial (ft)			Crater radius (ft)			Crater depth (ft)		
Dry rock	18	36	58	20	40	65	10	20	32
Dry soil	20	40	65	25	50	81	12	24	39
Saturated Clay Shale	18	36	58	27	54	87	13	26	42

Table 6

Supplemental Single-charge Crater Parameters

Parameter	Dry rock	Dry soil	Saturated clay shale
Lip crest radius (R_{al})	1.2 R_a	1.2 R_a	1.4 R_a
Lip height (H_{al})	0.25 D_a	0.15 D_a	0.45 D_a
Radius of continuous ejecta (R_{eb})	3.0 R_a	2.2 R_a	3.5 R_a
Radius of rupture zone at surface	4.4 R_a	--	4.0 R_a
Radius of rupture zone at charge elevation	1.1 R_a	--	2.0 R_a
True crater radius (R_t)	1.0 R_a	1.0 R_a	1.1 R_a

the extent of the ejecta, and the extent of the rupture zone are useful. In Table 6 these parameters are given in terms of crater radius, or crater depth, and apply to craters produced by charges detonated at optimum depth. With the exception of lip crest radius, these parameters may vary over a considerable range. The lip height, for example, may vary by a factor of two around the perimeter of a typical crater. Comparable variation may be expected for the radius of continuous ejecta and the size of the rupture zone.

Ground Motion. Ground motion will accompany all subsurface detonations and may cause structures on and beyond the construction site to move or vibrate. The amount of explosive energy coupled to the medium and transmitted as seismic energy depends on the conditions of emplacement, depth of burial, and type of surrounding medium. The coupling effect or seismic efficiency becomes greater as voids surrounding the explosives are reduced, burial is deeper, and the medium is more competent (rock as opposed to soil). Typically less than 1% of the total explosive energy is converted into seismic energy.

The most influential factor governing the magnitude of the seismic signal received at any location is the geology at that location. Current data indicate that at large distances from the detonation point, the surface motion at a site located on soil can sometimes be five times as high as the surface motion at a site located on rock with other parameters being equal.

Particle velocity and acceleration are the ground motion parameters of interest and are also the parameters which most seismic instruments are designed to measure. Particle acceleration has been shown to have

fairly consistent values at which given levels of damage occur for residential structures. No similar correlation with damage to engineered structures such as high-rise buildings has been developed to date. The frequency of the ground motion is also important in determining the response of residential and high-rise or engineered structures, but the capability does not exist to predict reliably the frequency of peak ground motions.

Four curves for charge yields of 1, 10, 100, and 1000 tons of TNT are given in Figure 6 which predict peak ground acceleration as a function of range for several medium conditions, both at the detonation site and at the point of interest. Because of the large dependence of motion on the shock propagating medium, it is always prudent to do calibration detonations at the specific site and make specific measurements at points of interest.

Airblast. For underground detonations at cratering depth, damage due to ground motion and missiles will usually be dominant, and safety concern from airblast is generally limited to ranges where broken windows could cause personal injury. The range at which airblast effects may cause damage or injury is a function of the charge size, number of charges, burial depth, and atmospheric conditions at detonation time.

After the initial shock front from an underground explosion strikes the ground-air interface, a wave disturbance in the air is generated by the sudden mound growth of the displaced earth. The wave then propagates through the atmosphere at a velocity determined by meteorological conditions. This portion of the air overpressure wave is termed the "ground-shock-induced airblast".

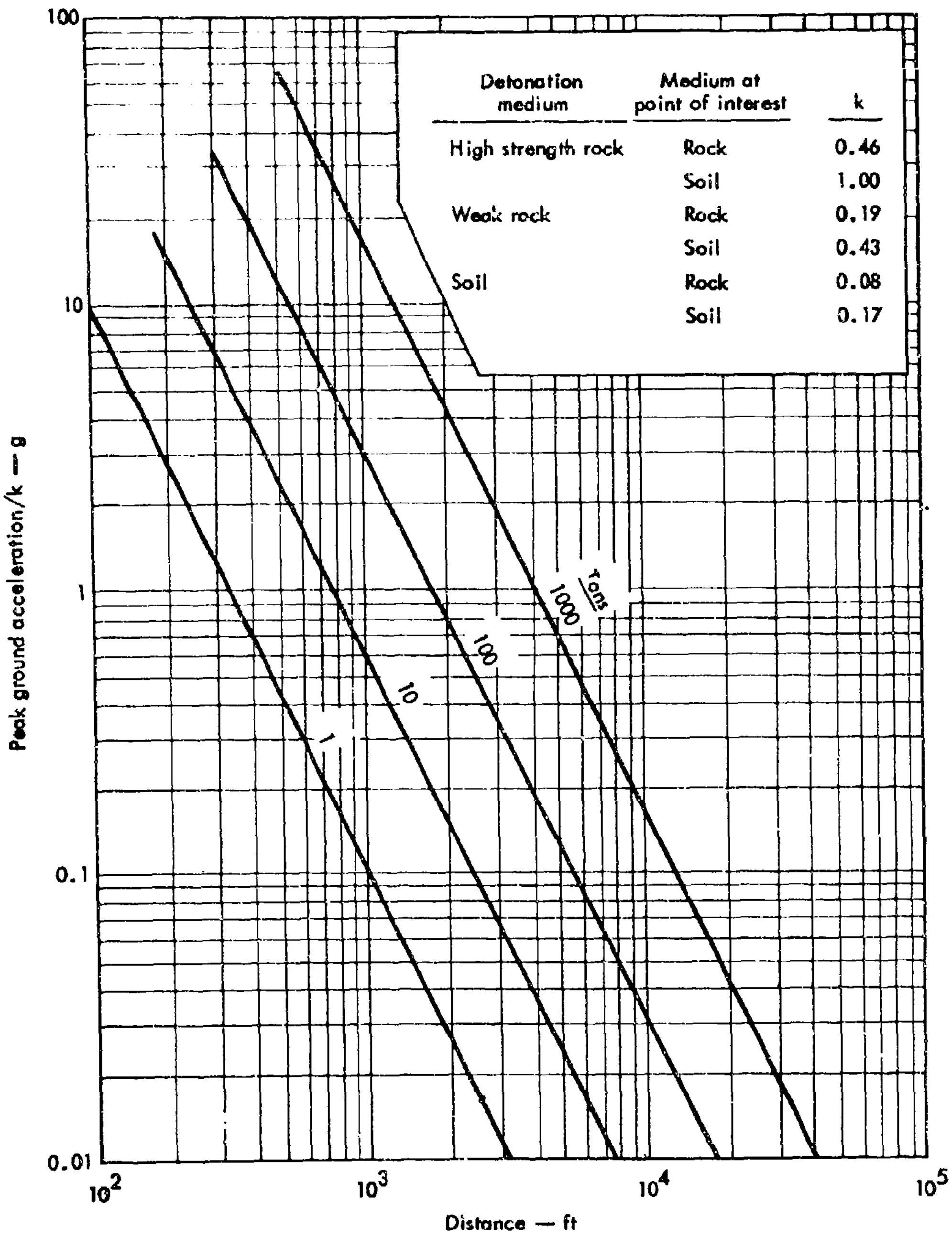


Figure 6. Ground Acceleration Predicitons

As the gas bubble generated by the underground explosion expands toward the ground-air interface, it transfers additional velocity to the overlying soil and rock. The specific pressure of this gas bubble when it "vents" will determine the magnitude of the second part of the air overpressure wave, which is called the "gas-vent airblast pulse". This occurs at the time of venting. If the pressure of the gas produced by the explosion is equal to or less than atmospheric when it finally breaks through the rising mound of earth, there will be no observable gas-vent airblast pulse. This condition is dependent on the depth of burial of the charge, the explosive used, and the specific properties of the detonation medium.

Thus two distinct pressure wave peaks may exist and be measured from an underground explosion. It is the wave with the highest peak overpressure (highest pressure above ambient) that is of interest in the development of airblast prediction procedures.

A proven prediction procedure has not yet been fully developed which adequately handles both of these peak pressure pulses. However, work now underway at EERO is expected to result in a good comprehensive procedure that will cover all conditions of depth of burst, explosive and media for which some experience exists. Even with such a prediction procedure there will still be uncertainties introduced because of limitations on the ability to predict specific meteorological conditions which affect the propagation of the airblast pressure pulse through the atmosphere.

Currently, peak airblast overpressure amplitude is predicted by scaling the overpressure expected from a 1000-ton explosive charge of TNT detonated in a standard atmosphere with zero sound velocity gradient to the proper yield. This overpressure data is then reduced by an empirically determined

factor which is a function of the depth of burst. The standard overpressure-range curve for the 1000-ton TNT "free" airburst that is used is designated the "IBM Problem M" curve and is given in Figure 7. Curves for other charge weights (Y) and pressure conditions (P) may be constructed by shifting the Problem M curve up or down according to the relation:

$$\Delta P = \Delta P_m \left(\frac{P}{P_m}\right),$$

and moving the curve right or left according to the relation:

$$R = R_m \left(\frac{YP_m}{Y_m P}\right)^{1/3},$$

where

P = atmospheric pressure

ΔP = peak overpressure amplitude

R = range

Y = weight of explosive

Subscript m denotes data taken from the IBM Problem M curve (P_m = 1000 mbar)

The curves for explosive weights of 1, 10, and 100 tons detonated in free air at standard pressure conditions have been scaled and are also plotted in Figure 7.

The factor used to relate the levels of overpressure for air burst and subsurface detonations is called the airblast transmission factor (TF). The transmission factor is defined as the ratio of peak overpressure amplitude, ΔP, for a subsurface detonation to that expected at the same range from the same weight of explosive detonated in free air, or

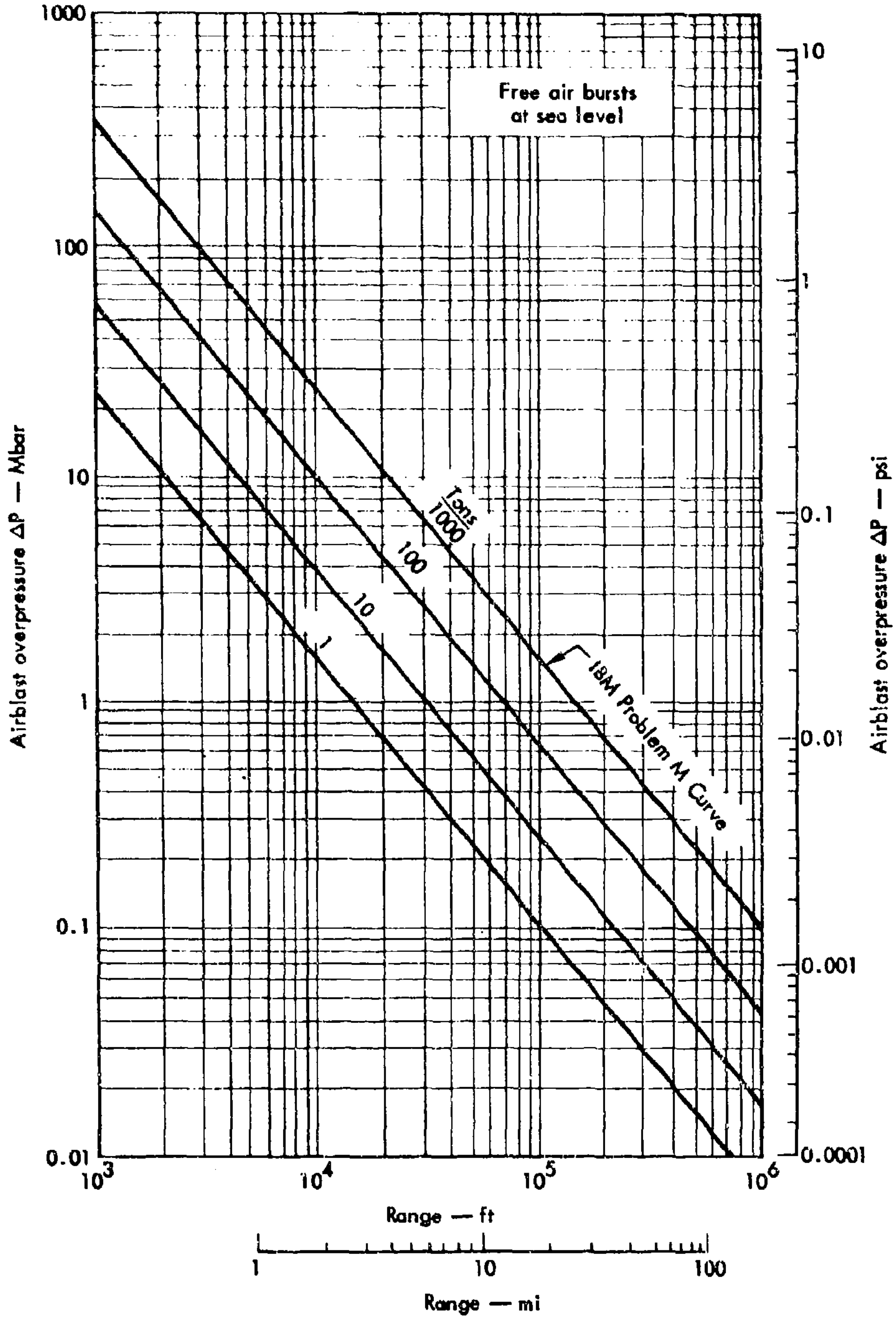


Figure 7. Airblast Overpressures from Explosive Detonations (adapted from ref. 3)

$$TF = \frac{\text{subsurface burst overpressure}}{\text{free air burst overpressure}}$$

$$= \frac{\Delta P_{\text{subsurface}}}{\Delta P_{\text{airburst}}} .$$

Figure 8 is a plot of the transmission factor as a function of scaled depth of burial in the region of general interest for explosive excavation applications.

Underwater shock. The shock wave produced by a detonation in water can be lethal to swimmers, divers, or marine life, and can damage underwater structures. The underwater shock from a detonation in a geologic medium overlain by water will be considerably reduced in magnitude compared to the ground shock from a corresponding land cratering detonation. The factors which govern the injury or damage that will be sustained are: (1) proximity to the source of the blast, (2) size and character of the explosive, (3) the degree of submersion of the receiver (swimmer, diver or structure), (4) the influence of boundary reflections, (5) the duration of the pressure pulse, and (6) the location of the charge with respect to the medium-water and water-air interfaces.

Investigations of detonations in a medium overlain by shallow water show two trends: first, the shallower the water the faster the rate at which peak pressure attenuates; and second, the magnitude of the peak pressure decreases at a particular range as the charge is moved from the medium water interface to below it (reference 6). Figure 9 and 10 may be used to estimate the peak pressures at various ranges for charges below the bottom in shallow water ($D/Y^{1/3} < 0.6$) which is the general region of interest for explosive excavation projects. In the figures, water depth, D, is in feet; charge, Y, is in pounds and charge depth below the water surface, Z, is in

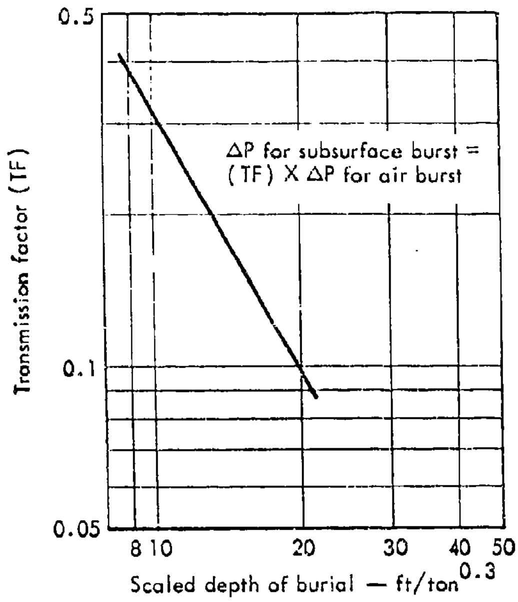


Figure 8. Airblast Transmission Factor for Underground Detonations (adapted from ref. 5)

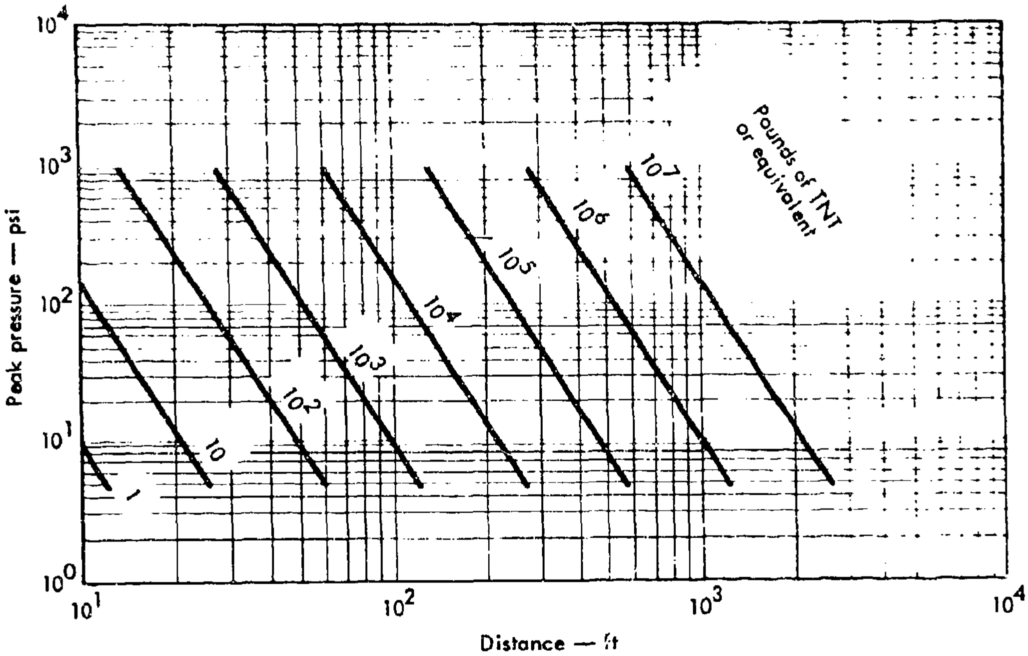


Figure 9. Underwater Shock from Explosions in Medium Overlain by Water for $Z = 1.9D$ and $D/Y^{1/3} = 0.292$. Z is the Charge Depth Below the Water Surface, D is the Water Depth, and Y is the Explosive Yield in Lbs.

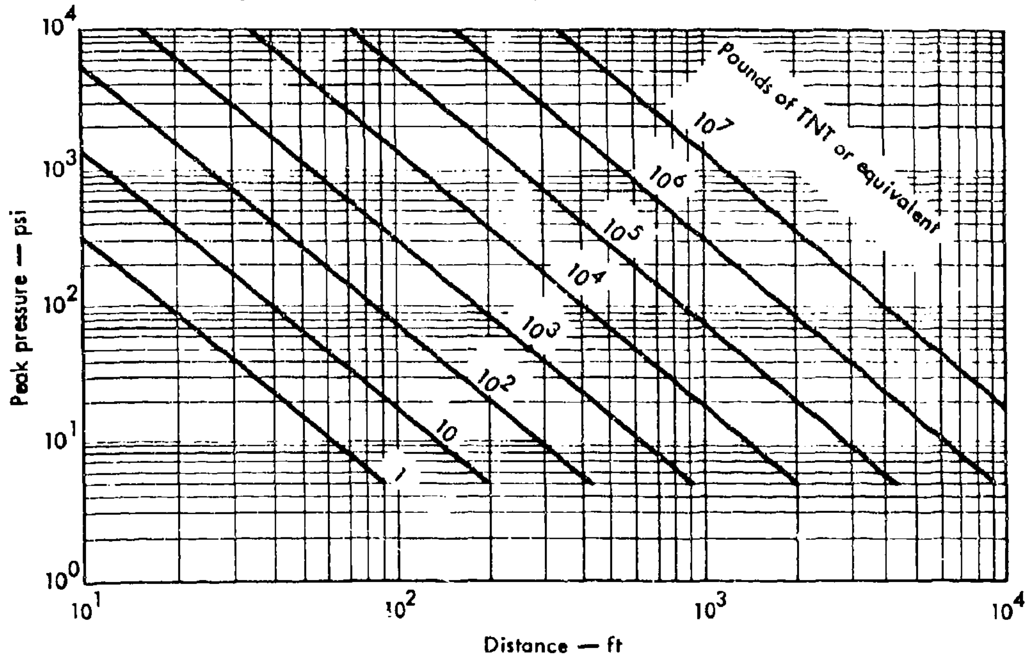


Figure 10. Underwater Shock from Explosions in Medium Overlain by Water for $Z = 1.225D$ and $D/Y^{1/3} = 0.585$.

feet. The validity of the curves in Figures 9 and 10 for other than the Z/D and $D/Y^{1/3}$ values given have not been established.

Water waves. Water waves generated by explosions in a medium overlain by water can be of significant size and can cause damage to waterfront installations such as seawalls, breakwaters or piers. Small boats in the area could be upset. Also, wave run-up on a shore could cause damage to structures and equipment.

The maximum height of waves generated by a single-charge or multiple-charge array buried beneath the sea floor can be predicted by using the curve in Figure 11. This curve is based upon data from Project TUGBOAT and its validity for all possible stituations has not been tested.

Missiles. Missiles from the detonation of buried charges that extend beyond the range of continuous ejecta pose a special hazard. Property such as motor vehicles, construction equipment, buildings and other structures can be damaged by missile impacts. Thus, the missile hazard is important in selecting safe separation distances for personnel and equipment, as well as in planning for and analyzing the effects of an explosive excavation detonation.

In evaluating the missile hazard to personnel and mobile equipment, the maximum range of missiles is the principal concern.

For buried explosives in the range of 0.5 to 500 tons, the depth of burial influences the range of missiles. Figure 12, developed from field data, may be used for the prediction of maximum missile range.

When used for personnel safety considerations, ranges calculated from the above relationships should be multiplied by a safety factor of 2, especially in those cases where the surface ground zero area is other than horizontal.

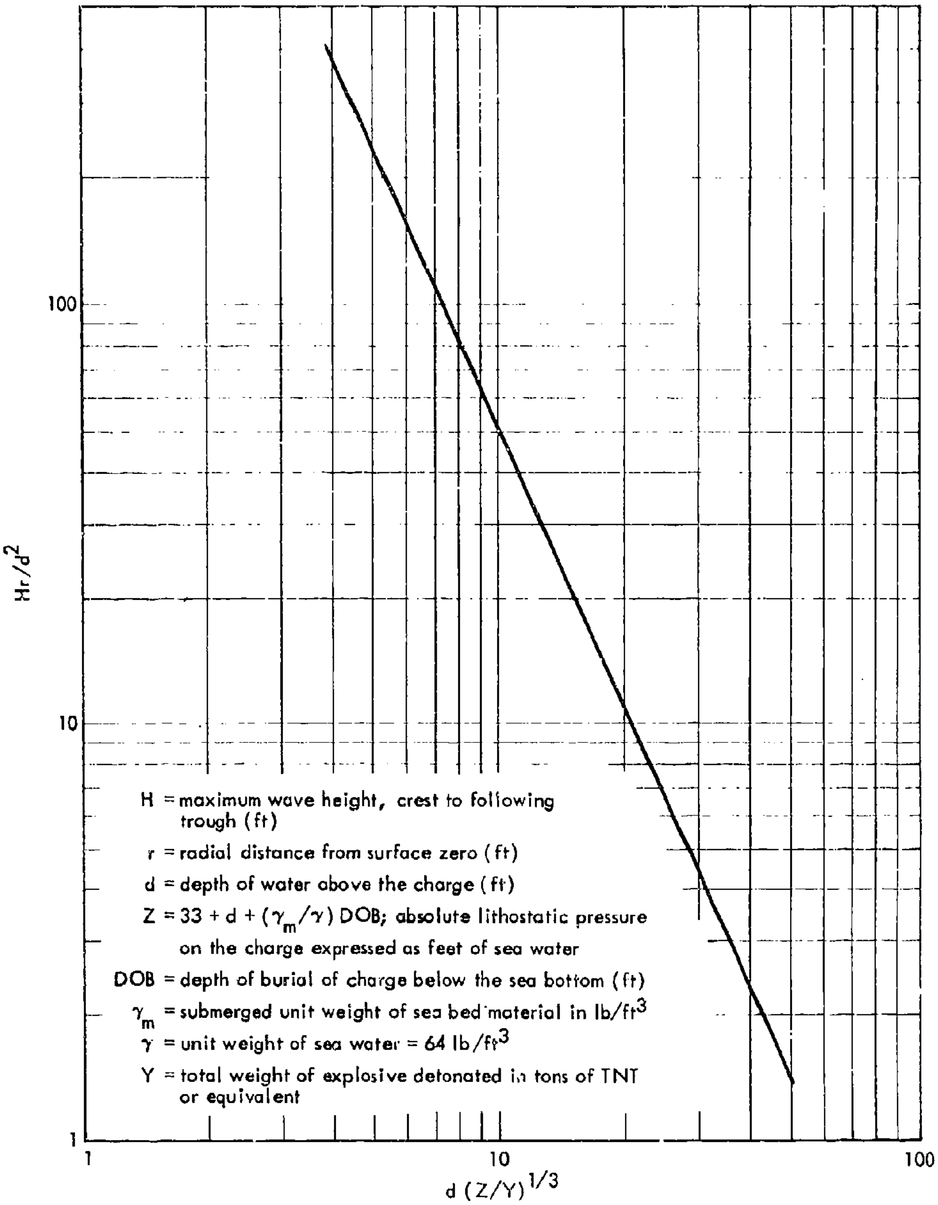


Figure 11. Maximum Water Wave Height Generated from Charges Detonated in Medium Overlain by Water

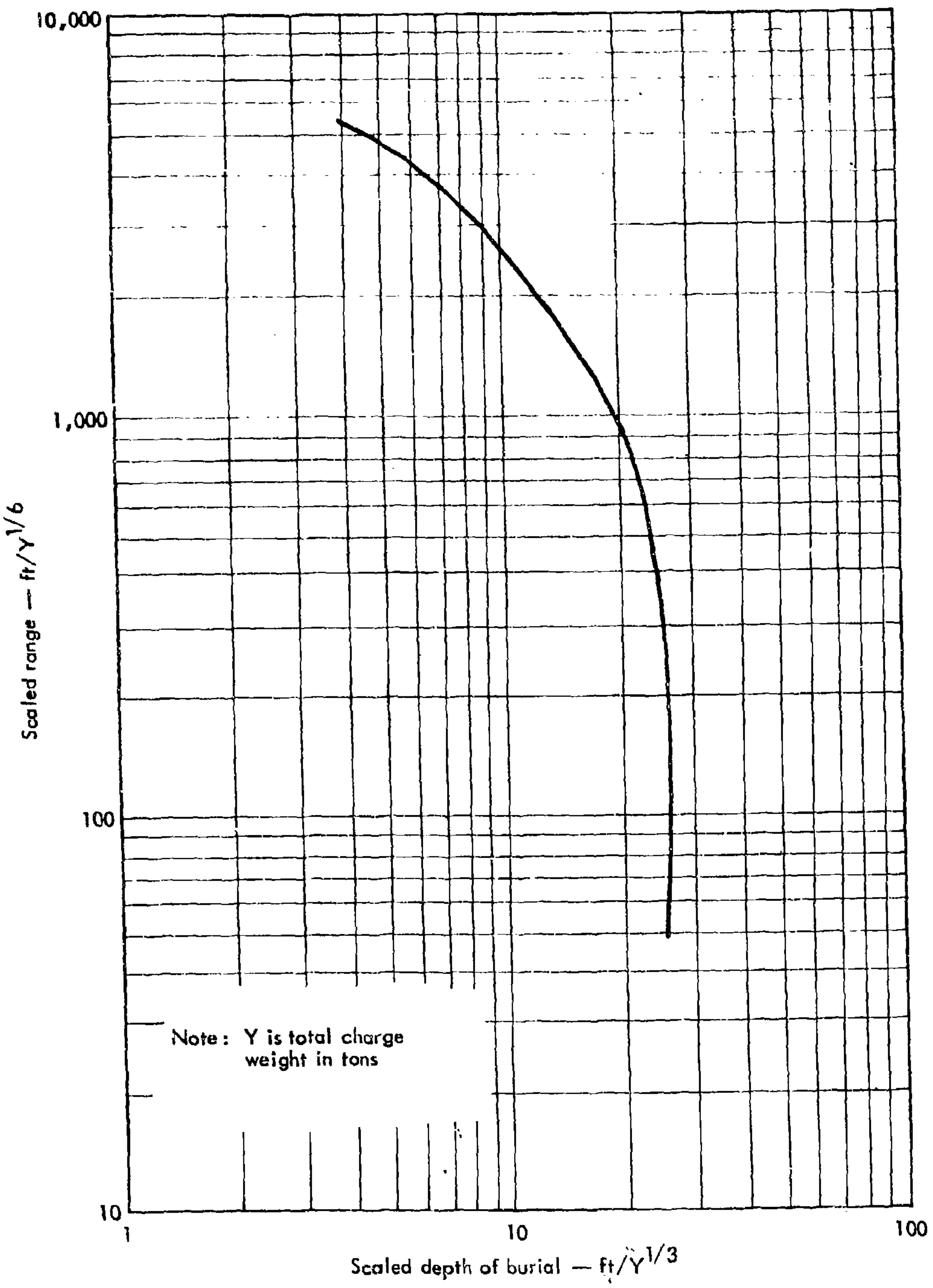


Figure 12. Prediction of Maximum Missile Range from Detonation of Buried Charges (from Ref. 7)

Summary

A research program in explosive excavation is providing experience in detonating relatively large charges underground at depths designed to crater or mound. Individual charge yields have ranged from about one ton to approximately 85 tons, and total detonation yields of multiple charges up to 210 tons have been fired. The explosives used in the major tests have been TNT, nitromethane, ANFO, and aluminized ammonium nitrate slurries. Charge shapes have been either spherical or cylindrical with height to diameter ratios of up to 3:1. Experience has shown that of the many explosives and blasting agents available for the main explosive excavation charges, the ammonium nitrate base explosives seem to offer the most cost advantage. The primary explosive characteristics desired are a high gas bubble energy, a high heat of detonation, an impedance ratio with the medium between 0.2 and 1.0, and a detonation pressure under 150 to 200 kbar. The explosive should have sufficient density to displace water if necessary, it should have a high-water resistance if emplaced in very damp of wet boreholes, it should be classified as an oxidizing material to minimize shipping costs, and it should have a high viscosity in the emplaced configuration when needed. With appropriate additives the ammonium nitrate base explosives can be made to meet any of the appropriate characteristics from those above that would apply in a particular case.

Effects measurements including crater dimensions, ground motion, airblast, underwater shock, water waves, and missile ranges have been made which have led to a general prediction capability. This prediction capability is continually being revised and updated as research results and new test data warrant.

References

1. Johnson, S. M., et. al., NCG Technical Report No. 21, Explosive Excavation Technology, U. S. Army Engineer Nuclear Cratering Group, Lawrence Radiation Laboratory, Livermore, California, June 1971.

2. Vortman, L. J., "Ten Years of High Explosive Cratering Research at Sandia Laboratory," Nuclear Appl. and Tech. 7 269(1969).

3. Reed, J. W., "Airblast from Cratering Explosions," in Proceedings of the Third Plowshare Symposium, April 21, 22, and 23, 1964, (University of California, Davis), Lawrence Radiation Laboratory, Livermore, and San Francisco Operations Office, U. S. Atomic Energy Commission, Rept. 770-7695.

4. Military Engineering With Nuclear Explosives, U. S. Army Engineer Nuclear Cratering Group, Livermore, California, Rept. DASA 1669, June 1966.

5. Reed, J. W., Microbarograph Measurements From Underground Tests (U), Sandia Laboratories, Albuquerque, New Mexico, Rept. WT 9006, December 1964 (CRD).

6. Effects of Explosions in Shallow Water, Final Report, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Rept. TM 2-406, April 1955.

7. Vortman, L. J., Maximum Missile Ranges From Surface and Buried Explosions, Sandia Laboratories, Albuquerque, New Mexico, Rept. SC-RR-67-616, September 1967.

ENTRAPPED AIR HAZARD IN PRESSING OF EXPLOSIVES†

I. B. Akst

DEVELOPMENT DIVISION

Mason & Hanger - Silas Mason Co., Inc.
Pantex Plant
Amarillo, Texas

APRIL 1971

†*Work sponsored by the U. S. Atomic Energy Commission, Albuquerque Operations Office, Albuquerque, New Mexico*

ENTRAPPED AIR HAZARD IN PRESSING OF EXPLOSIVES

I. B. Akst

April 1971

Whether air in the press cavity during "hydrostatic" or "isostatic"(1) pressing of explosives constitutes a potential explosion hazard, because of being heated by compression, is a question which has been raised more than once.

If one assumes that air in the cavity is compressed adiabatically, the temperature rise would, of course, be very great in compression from atmospheric pressure to 20,000 psi.

The maximum amount of heat transfer energy available from the compression of air is the energy stored assuming an isentropic expansion (adiabatic, reversible). Thus, the available energy due to an adiabatic compression of air from normal conditions to 20,000 psia can be calculated as an estimate of the total energy and temperature increase available for potential ignition of the HE. Since the thermodynamic properties of most gases deviate significantly from the ideal gas equation-of-state at high pressures, a literature search was conducted to collect the desired high pressure data for air. Numerous references were obtained, but most data were presented only to a pressure of 100 atm (1500 psia)(2,3) although Obert(4) included values for the specific heat of air up to 15,000 psia. Consequently, since a scarcity of data was apparent for the higher pressures, the "compressibility" concept for an equation-of-state of the form

$$pV = nZRT \tag{1}$$

was considered where

- P = pressure
- V = specific volume
- n = number of moles
- Z = compressibility factor (non-dimensional)
- R = gas constant
- T = absolute temperature

The "Z" factor can be readily determined from a generalized chart for most gases within 5 to 10% error by using reduced properties ($P_R = P/P_c$, $T_R = T/T_c$) where subscripts are r = reduced and c = critical.

Since the determination of the "Z" factor is dependent on two properties of state, another property in addition to the pressure at 20,000 psia was necessary to determine the "Z" factor(5). Therefore, as a first approximation a temperature was calculated based on the ideal gas equation for isentropic compression:

$$T_2 = T_1 \, (P_2/P_1)^{\gamma-1/\gamma} \tag{2}$$

An average value for γ, the ratio of specific heats, was assumed at 1.36, based on the initial value of 1.40 and the final value at close to 1.32. The pressure and starting temperature is assumed as $T = 298$ K = 25 C or 77 F. $T_2 = 298(20{,}000/14.7)^{.265}$ = 2010 K = 1740 C or $\sim$ 3160 F.

Such a temperature is obviously high enough for fast initiation of explosives.

But the situation may not be adiabatic: instead of the air being in a large isolated pocket, it might be distributed in smaller quantities through the cavity and powder.

Let us examine that situation. In pressing of loose molding powders, the HE/air system should be nearly isothermal for the granule sizes and times involved. Since there is a much greater mass of explosive than air, the resultant temperature rise of the system would be very small:

Assume there is 100 pounds of powder having a bulk density of 1.0 g/cc, to be pressed to a density of 1.86 g/cc or 98% of the theoretical maximum density of 1.88 g/cc. The powder (HE and air) would initially occupy a space of 45,400 cc, final space of 24,400 cc of which 24,150 is explosive and 250 cc is air, the initial air being 21,250 cc:

$$q = M \cdot C \cdot \Delta T \qquad C_{air} \sim C_{HE} \sim 0.25 \text{ cal/g/}^\circ\text{C}$$

M = Mass
q = heat quantity

$$M_{air} = V \cdot \rho = 21{,}250 \text{ cc} \cdot .0012393 \text{ g/cc}$$

$$\sim 26 \text{ g}$$

$$q = 26 \times .25 \cdot 1710$$

$$\sim 11{,}000 \text{ cal}$$

$$\Delta T_{HE} = q/M_{HE} \quad C = 11{,}000/45{,}400 \cdot .25 \sim 1 \text{ C}(6)$$

These calculations indicate that air in powder will not be a cause of HE ignition by increasing the bulk temperature, if the air is distributed and is therefore actually not adiabatically compressed but transfers heat continously and quickly to the HE during compression.

There is a slight amount of adiabatic heating of the whole mass, however, by the compression of the HE itself. It has been measured experimentally(7) to be in the region of 5 to 10 C. Much of that small amount of heating is reversible, as expected, dropping off to within 2 to 5 C of the starting temperature when pressure is released. (The residual temperature increase

of a few degrees is thought to be frictional heating by the work of pressing.) The presence of air does not change these figures, as may be seen in the curves from experiments described below, which were done to check the isothermal theory.

Experiments were done in an 8-inch press, using mock HE (90010) powder, in a dry bag instrumented with a copper-constantan thermocouple connected to a strip-chart recorder. In the first experiment vacuum was applied to the powder until a gage very close to the press cavity read approximately 1 mm Hg steady pressure. In the second experiment, no vacuum was applied, and the system was sealed off to prevent the escape of air. (That air escape was minimal, if there was any at all, was attested to by the delamination and crumbling of the billet when taken from the press, as contrasted to the solid high-density billet resulting when vacuum was applied—which is the very reason vacuum is used in totally enclosed pressing.)

It may be seen from the curves in Fig. 1 that the presence of air had little effect on the temperature in the cavity. The bulk compression heating, mentioned above, is observed as approximately 14 F rise and 7 F drop upon depressurization.

From these calculations and the experimental verifications, it is concluded that air distributed in HE molding powder will not cause a hazardous rise in temperature by compressional (PdV) heating. (Whether reactivity of explosives increases with pressure was studied with some O_2 present in a high-pressure differential thermal analysis (DTA) apparatus. It was found(*8*) that there was no essential change in reactivity of present bulk-use explosives.)

If the air were not distributed with some degree of uniformity, but could exist in a bubble or pocket of significant(*9*) size, the situation could be quite different and undesirable temperature rises might be experienced.

Some of the calculations above indicate how high an adiabatic temperature might be. But the variety of possible configurations, the attendant conductivities, etc., preclude high-confidence calculations of real maximum temperatures. Therefore, a few scouting experiments were done. Their results demonstrate that undesirably high temperatures can be achieved.

The essentials of the experiments were thus: a rubber cylindrical sac, closed on one end with a flat surface and open at the other end, was placed open-end down into the pressurizing fluid of the 8-inch press, so as to trap the air in the sac. A 0.005-inch copper-constantan thermocouple was inserted so that the junction was at or near the top of the air cavity. Its output was recorded on the y-axis of a single-pen recorder, with time as the x-axis, while noting pressure, (read from the press control console gage) on the recorder chart.

The maximum temperature so recorded was approximately 300 F with the experiment starting at room temperature, for a rise of about 220 F. The curve of Fig. 2 was taken from the recording of a run that reached approximately 200 F and was especially useful, showing clearly the phenomena involved.

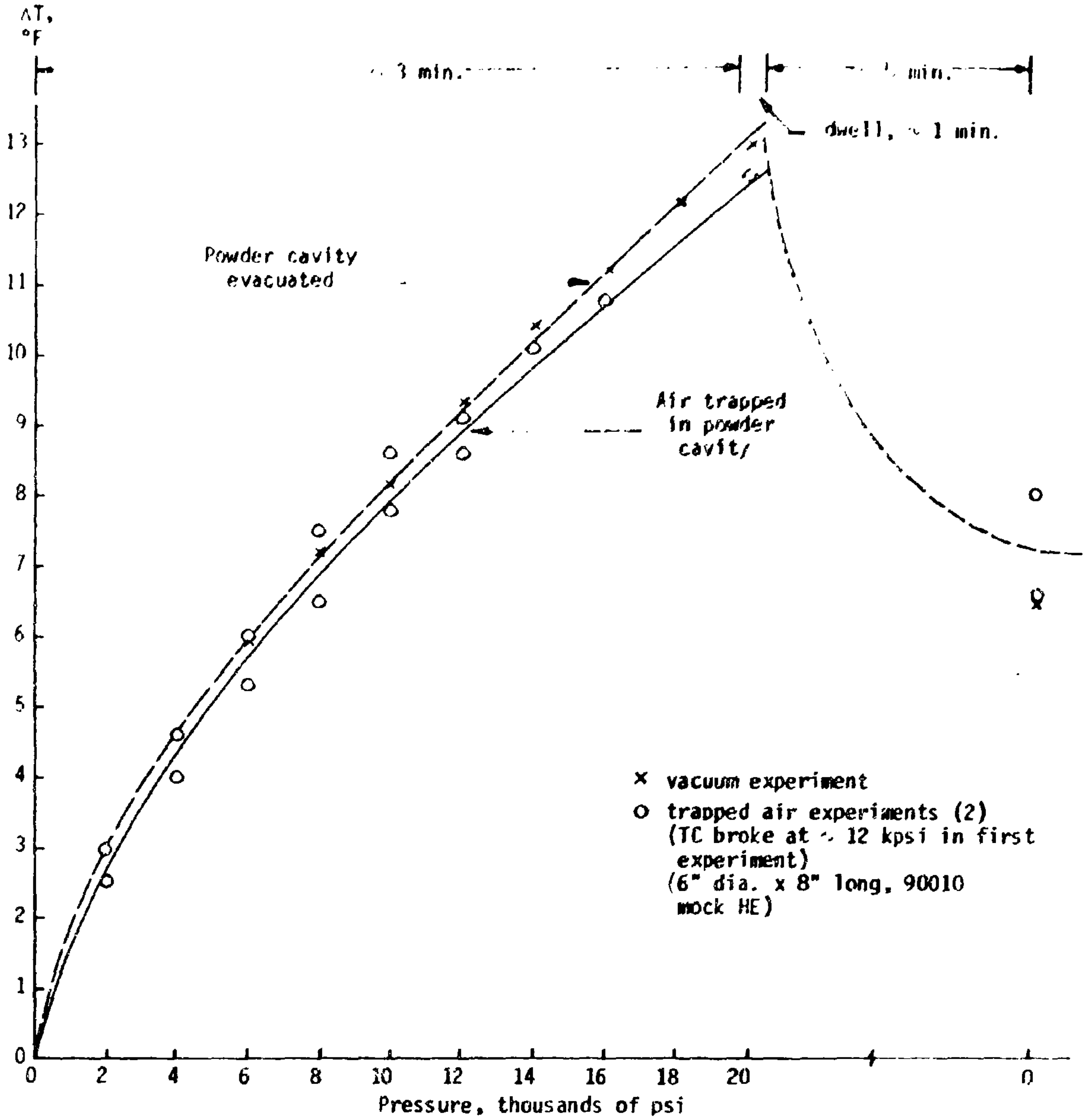


Fig. 1. Pressure-induced temperature rise in powder

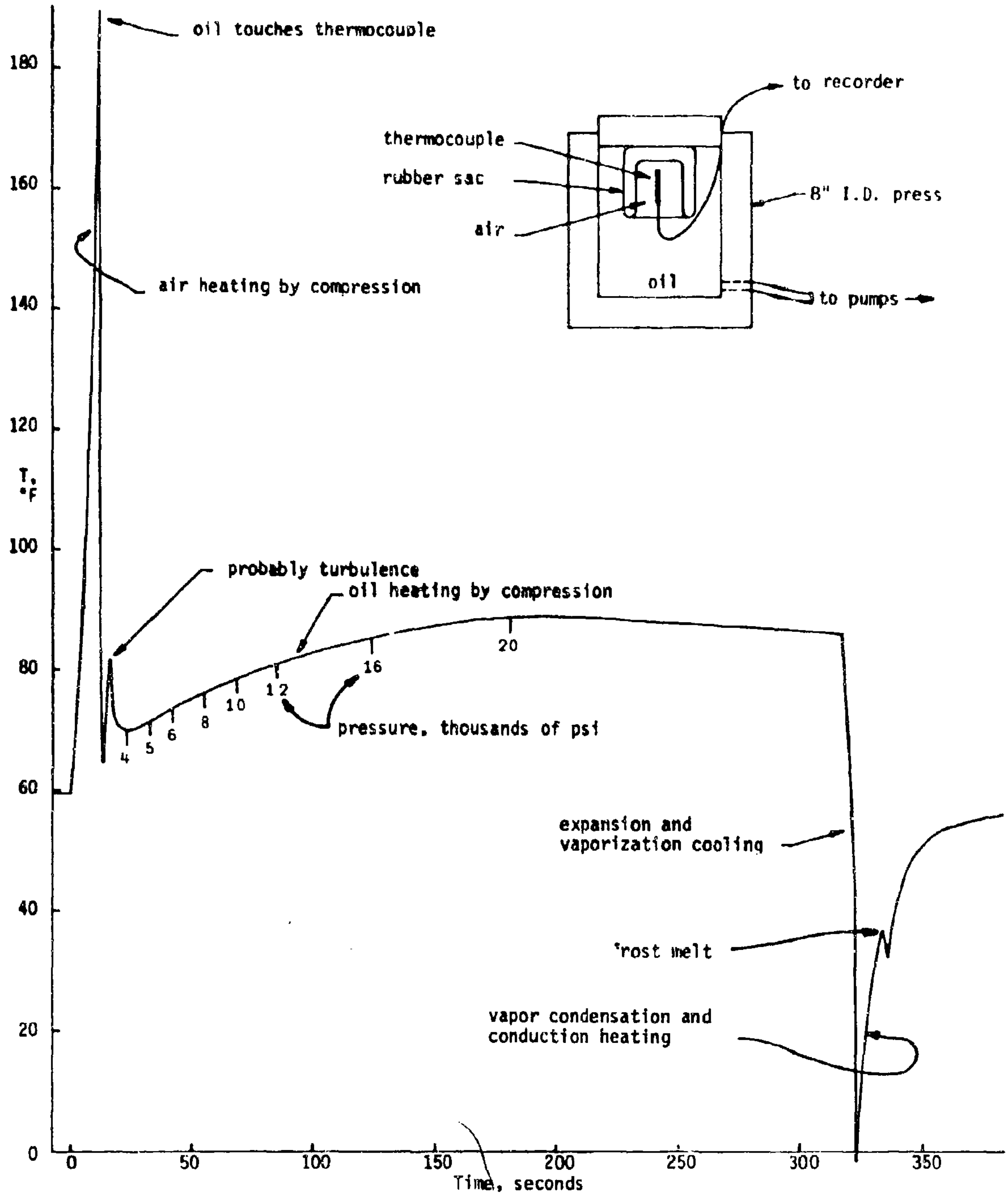


Fig. 2. Temperature during pressurization and depressurization of a large air bubble

The flat-topped sac prevents very high temperature rises because the pressing fluid reached the thermocouple junction easily with only a few hundred psi pressure—dependent on flatness, tilt, etc.—and cools it as well as the air. For that reason, experiments were done in cones and spheres, the thermocouple being positioned just below the apex.

The recorder response time was reduced and the experiments included observations of the liquid level, and also included effects of exposure to water vs. oil as the pressurized fluid medium.

In a preliminary experiment an air bubble was trapped in a Fiberglas-epoxy cone. Upon removal from the press, after pressurizing, the inside tip region of the cone was scorched black.

In other experiments, a nitrogen bubble was formed in a Pyrex cone that had a volume of 1225 cc. The open bottom of the cone was sealed against air by flooding with an electrically conductive fluid (distilled water with 0.25 weight percent copper sulfate in solution) to measure liquid level in the cone by short-circuiting pairs of wires. The experimental arrangement and results are shown in Fig. 3.

All the variables could not be observed simultaneously, but required multiple compression cycles. The data shown in Fig. 3 were extracted from some portions of several cycles and tests.

In still other experiments, a thermocouple was fixed adjacent to the inside polar surface of a pre-pressed hemispherical shell of mock HE (90503) as shown in Fig. 4. The shell was then inserted into the pressing fluid, thus capturing an air bubble. Measurements were made of the temperature increase resulting when the fluid was water and also with oil-based hydraulic fluid.

The curves of Fig. 4 show the temperature histories. The inside top portion (2-1/2-inch diameter) of the mock HE was scorched black in the test using oil.

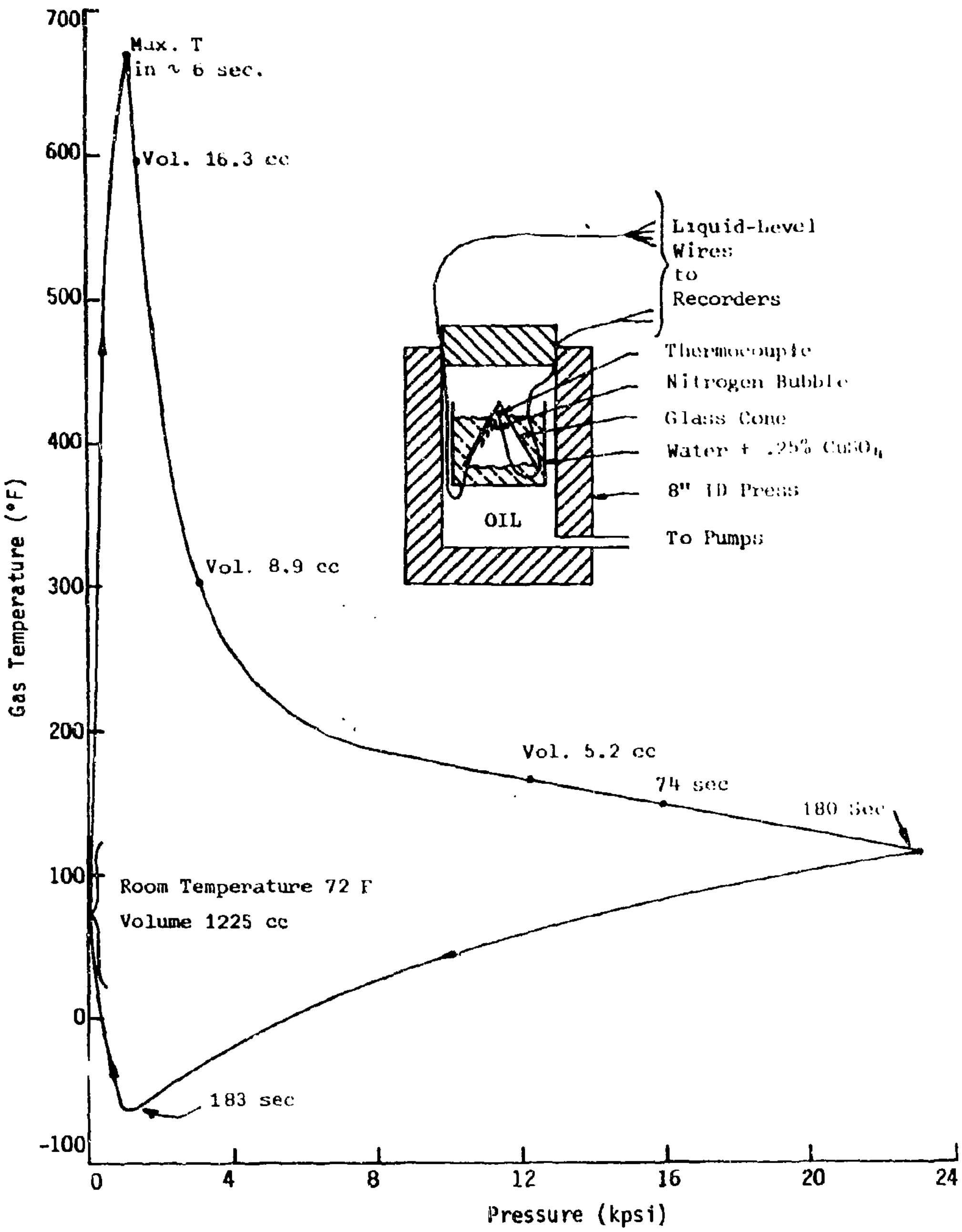


Fig. 3. Temperature in Nitrogen Bubble during Compression and Decompression Cycle

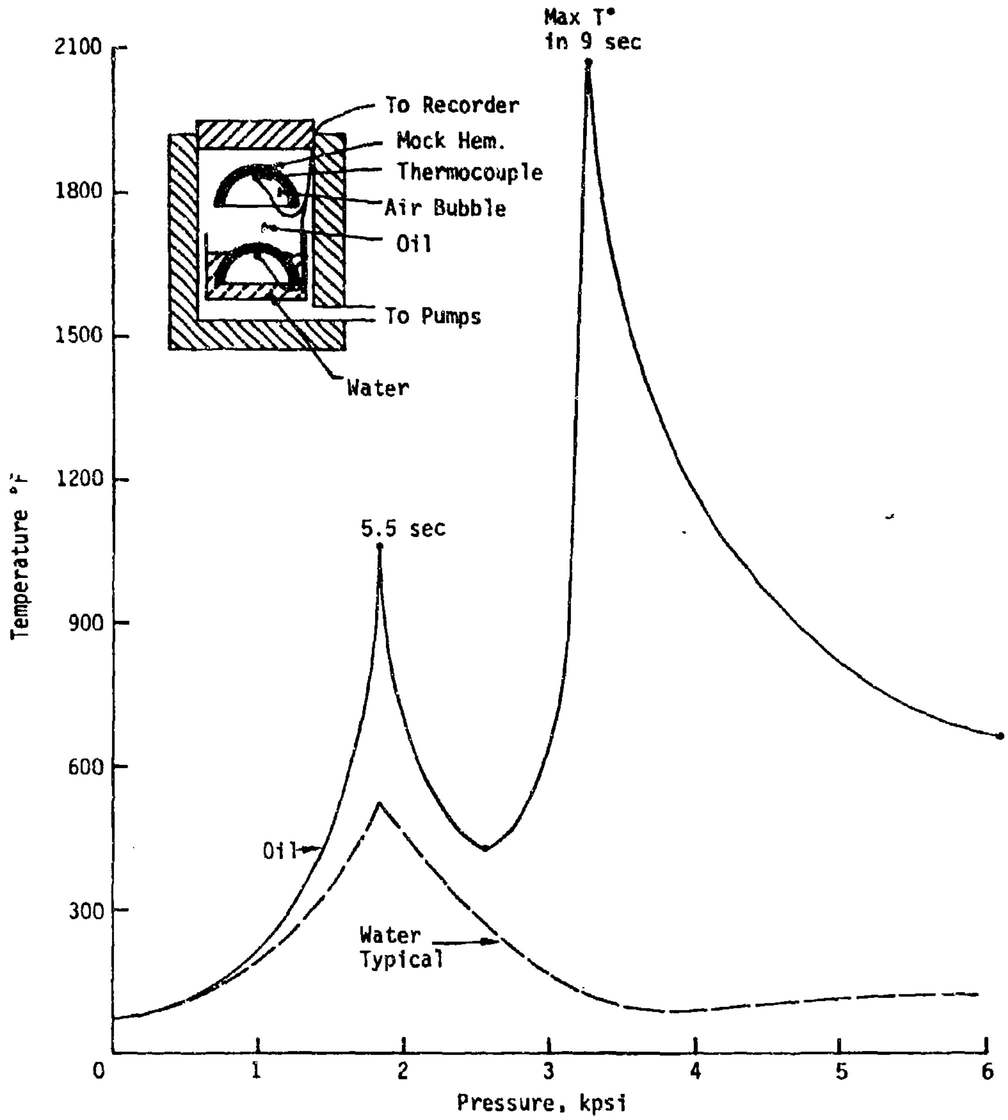


Fig. 4. Temperature in Air Bubble During Early Compression

CONCLUSIONS

It is concluded that high temperatures can be reached by compressional heating, if there is a large pocket of air in the press cavity. Such pockets are conceivable if hollow open mandrels or pre-pressed charges having open cavities were used and were not filled before pressurizing. On the other hand it is also concluded that air distributed in a particulate solid presents no hazard from increase in temperature caused by compressional heating, nor from increased reactivity with explosives presently in quantity usage.

Repressing HE parts directly in the hydraulic oil can cause ignition of the oil vapors if an air bubble is occluded. The "dieselizing" situation can be avoided by exposing the HE parts to only non-flammable liquids during repressing operations.

The curves show that cooling of a gas bubble is relatively fast. That suggests a way of preventing high temperature rises: mechanically limit the rate of pressure application so that there is time to cool in any configuration, with any material. The added pressing time need not be more than a few minutes.

ACKNOWLEDGMENTS

The calculations by F. I. Honea and J. H. Van Velkinburgh, and the experimental work by J. D. Harrell, are gratefully acknowledged.

REFERENCES AND NOTES

1. Also called "dry-bag" and "wet-bag," respectively.

2. Perry, John H., Chemical Engineers Handbook, Third Edition, (1950).

3. Obert, Elements of Thermodynamics and Heat Transfer, McGraw-Hill, New York.

4. Tables of Thermal Properties of Gases, U.S. National Bureau of Standards Circular 564 (1955).

5. The "Z" factor determined from the reduced properties of T_2 = 2010 K (T_R = 15.2) and P_2 = 20,000 psia (P_R = 35.5) was indicated as Z = 1.22 from Table 40 in Perry(2). Subsequent use of Equation (1) led to a value of specific volume of V_2 = 0.082 cu. ft/lb and a ratio of V_1/V_2 = 165/1. As a verification of the estimated final temperature (T_2), an entropy balance was made for the entropy change due to temperature increase and pressure increase. The integrated entropy values indicated an agreement within 2.6% (making further iterations for temperature and "Z" factor unnecessary).

   Since any thermodynamic state point is independent of path or process, the calculation of the enthalpy change (ΔH) due to the compression can

be expressed as two steps: (1) constant temperature and (2) constant pressure. Thus, $H = f(P,T)$ or, integrating partials:

$$\Delta H = \int_{T_1}^{T_2} \left(\frac{\partial H}{\partial T}\right)_P dT + \int_{P_1}^{P_2} \left(\frac{\partial H}{\partial P}\right)_T dP$$

$$\approx C_{P_2} (T_2 - T_1) + (C_{P_2} - C_{P_2})/(T_2 - T_1) \left[(T_2^{\,2} - T_1^{\,2})/2)\right]$$

$$+ T_2 \left(\Delta C_{P_{P_1}} + P_2\right)_{T_2}$$

Substitution of values for $C_{P_1} = 0.204$ at $T_1 = 298$ K and $C_{P_2} = 0.297$ at $T_2 = 2010$ K yielded a value of $\Delta H = 480.2$ cal/g which is the total PV plus internal energy increase for the air.

From the First Law of Thermodynamics, the internal energy (ΔU which is available for the heating of HE) is

$$\Delta U = \Delta H - \Delta(PV) \tag{4}$$

Using Equation (4), a value of $\Delta U = 347.2$ cal/g was obtained.

6. Considering the same 100 pounds HE, the total maximum compression energy available from the air is $M_{air}\ \Delta U = 9030$ calories and the resultant temperature rise in the bulk HE is only $T = 9030/(MC_P)_{HE} = 9030/(100 \cdot 454 \cdot 0.25) = 0.8$ K

7. Quarterly Progress Report, Mason & Hanger, Pantex to LRL, 1st and 2nd Qtr. 1962 and 4th Qtr. 1961.

8. L. C. Myers, Mason & Hanger, Pantex, 14th Meeting of US-UK JOWOG 9, April 1970.

9. Large enough to approach an adiabatic condition, i.e. $(\Delta T/\Delta t)_{r=0} \to 0$, where t is the time and r is distance from the center of the bubble.

CLOSING REMARKS

Colonel William Cameron III, USAF
Chairman, Armed Services Explosives Safety Board

The 13th ASESB Seminar has run its course. Your attention and presence at the various presentations has indicated a high interest in explosives safety -- in the subject material -- and in your strong desire to make the changes necessary in our dynamic environment.

Our participation this year has been worldwide. The United Kingdom, Australia, Canada, Germany, have representation, as well as almost every state in the union, plus all the Services. It is gratifying to tell you over 500 attendees registered - the largest group to ever attend our seminar.

Much of the credit for the mechanics of running a large seminar like this go to CDR Lavin of my office; however, we are to have a serious discussion concerning the proper procedures to enable a Navy Commander to get around a Marine Corporal guarding a Navy gate!

Looking forward to next years seminar - already we have ideas on how to improve it - change it - to make it more meaningful and challenging. I hope to persuade the Department of Labor and Department of Transportation to make presentations next year.

I have tried to personally thank each speaker and moderator of the special sessions. I want to express again my deep gratitude for their participation.

It has been a pleasure to welcome you, speak with you, and listen to you. Now, let me say goodbye. The 13th ASESB Seminar is officially concluded. Thank you one and all.

PRECEDING PAGE BLANK

ATTENDEES

ABEGG, DR. T.	IRECO Chemical, Salt Lake City, UT
ABERNETHY, D. F.	DCSPER, Washington, DC
ADAMS, E. C.	AFAL(DWTW), Eglin AFB, FL
ADAMS, G. E.	Honeywell Inc., Minneapolis, MN
AINSWORTH, D. E.	NOSSO, Pacific, San Diego, CA
AKST, I. B.	Mason & Hanger-Silas Mason Co. Inc., Amarillo, TX
ALG, R.	Hq USAF (IGDSOE) Norton AFB, CA
ALLAN, D. S.	Arthur D. Little, Inc., Cambridge, MA
ALLEY, R. C.	Lexington-Blue Grass AD, Lexington, KY
ANDERSON, D. C.	IIT Research Institute, Chicago, IL
ANDERSON, E. D.	McDonnell D. Astronautics Co., Santa Monica, CA
ARBUTHNOT, G. L., Jr.	USAEWES, Vicksburg, MS
ARMSTRONG, CAPT J. C.	AFWL, Kirtland AFB, NM
ASHCRAFT, F. M.	MAC, Scott AFB, IL
ATKISSON, J. B.	Jet Propulsion Lab., Pasadena, CA
BACHER, A. E.	CA Division of Highways, Sacramento, CA
BACHTELL, N. D.	ASESB, Washington, DC
BAILETS, R. J.	AFFTC, Edwards AFB, CA
BAILEY, M. R.	USAMC Fld. Safety Agency, Charlestown, IN
BAKER, CAPT R. W.	COMSERVPAC, STAFF, FPO San Francisco, CA
BALL, J. G.	NASA, Pasadena, CA
BALLANCE, N. B.	NOS, Indian Head, MD
BALOGH, CDR A. T.	NAD, Crane, IN
BANKS, Q. H.	DOT, Washington, DC

PRECEDING PAGE BLANK

BARKER, J. F.	Hq. 15th AF/DMW/SAC, March AFB, CA
BARNUM, COL F.	IGDSL, Norton AFB, CA
BECHER, A. F.	Edgewood Arsenal, MD
BELLES, F. E.	NASA/Lewis Research Center, Cleveland, OH
BELLIVEAU, L. T.	DNA, Washington, DC
BERTRAND, B. P.	BRL, Aberdeen Proving Ground, MD
BISHOP, R. H.	Wright-Patterson AFB, OH
BOBKO, J. R.	AFP Representative Ofc., Sunnyvale, CA
BORAWSKI, E. T.	NOS, Indian Head, MD
BORGELT, L. D.	Lockheed Propulsion Co., Redlands, CA
BORUM, DR. O. H.	Research Div., AMC, Washington, DC
BOUTON, S. L.	NOEF, Keyport, WA
BOUTWELL, F. K.	Delco Electronics-SBO (GMC) Goleta, CA
BOX, J. R.	DSQA, Robins AFB, Warner Robins, GA
BOYD, G. F.	Tri-State Motor Transit Co., Joplin, MO
BOYD, L. B.	USNWS, Yorktown, VA
BRADSHAW, CAPT, R. H.	CINCPACFLT, FPO SF, CA
BRASWELL, A. T.	Red River AD, Texarkana, TX
BRAUN, E. F.	DCASR, DSA, Detroit, MI
BREEDING, C. A.	ASESB, Washington, DC
BRENNAN, LCDR, J. J.	Naval Torpedo Station, Keyport, WA
BRETTEL, E. G.	Day & Zimmermann, Inc., Kansas AAP, KS
BRIGGS, D. L.	Internal Revenue Service, US Treasury, Wash., DC
BRISKIN, M.	Asst. General Counsel(Logistics), OSD, Wash., DC
BROOKS, E. L.	Pan American World Airways, Patrick AFB, FL
BROOKS, I. G.	AFSWC(SE), Kirtland AFB, Albuquerque, NM

BROWN, DR. B.	Hercules, Inc., Magna, UT
BROWN, H. O.	AFSWC(SE), Kirtland AFB, NM
BROWN, M.	DCASR, DSA, Chicago, IL
BROWN, W. D., Jr.	Iowa AAP, Burlington, IA
BROWNLEE, G. K.	Yuma Proving Ground, Yuma, AZ
BUNYAN, LCDR, L. P.	NWS, Charleston, SC
BURMAN, C. L.	AFLC, Wright-Patterson AFB, OH
BUSCHMAN, E. H.	NAD, Crane, IN
BUTAS, J. A.	Safeguard System Command, Huntsville, AL
BYERS, C. R.	Jet Propulsion Lab, Pasadena, CA
BYRD, LCDR, J. J.	NSC, San Diego, CA
BYRD, J. L. Jr.	AMC Ammunition Center, Savanna, IL
CAIN, J. F. Jr.	Western Elec. Defense Activities, Greensboro, NC
CALL, R. J.	Olin Corp, Marion, IL
CALLAHAN, H. L.	Black & Veatch, Kansas City, MO
CALLAWAY, ENS, M. A.	USN Amphibious Base, Coronado, CA
CAMERON, COL W. III	Chairman, ASESB, Washington, DC
CAMPBELL, C. J.	USA Weapons Command, Rock Island, IL
CAMPBELL, LTJG, L. M.	USN Amphibious Base, Coronado, CA
CAREW, D. L.	Aerospace Defense Command, Colorado Springs, CO
CARL, S. P.	DCASR, DSA, Atlanta, GA
CARMICHAEL, LTC G. F.	Langley AFB, VA
CARNES, R. N.	Mechanics Research Inc., Los Angeles, CA
CARNEY, R. E.	Hq Military Airlift Command, Scott AFB, FL
CARSON, E.	NWS, Charleston, SC
CARSON, COL J. S.	Hq Armament Development & Test Ctr., Eglin AFB,FL

CARSON, K.	NWS, Charleston, SC
CASHMAN, LCDR M.	EOD, Indian Head, MD
CATES, CAPT C. B., Jr.	NOSC, Washington, DC
CHATTLETON, CAPT W. D.	COMSERVPAC, Hq, FPO San Francisco, CA
CHILDRESS, W. L.	Thiokol Chemical Corporation, Brigham City, UT
CHRISTNER, R. F	Tinker AFB, OK
CLAPP, LT R.	USN Amphibious Base, Coronado, CA
CLARK, W. G.	Naval Undersea R&D Center, Pasadena, CA
CLAXTON, R. D.	Ogden AF Plant Rep. Ofc., Hill AFB, UT
CLEMENTS, L. C.	Gulf Energy & Environmental Systems, San Diego, CA
CODER, LTC J. D.	ASESB, Washington, DC
COEN, LCDR F. M.	USNAD, Hawthorne, NV
COFFIN, J. P.	Thiokol Chemical Corporation, Bristol, PA
COLBATH, L. E.	Tooele AD, UT
COLE, L. F.	USAMC, Rock Island, IL
COMBS, CDR M. F.	NAD, Oahu, FPO San Francisco, CA
CONLEY, J. H.	Aberdeen Proving Ground, MD
CONNELLY, J. W.	CNO, Washington, DC
COOK, DR. M. A.	IRECO Chemicals, Salt Lake City, UT
CORDLE, LCDR J. T.	USNWS, Seal Beach, CA
COUCH, G.	United Technology Center, Sunnyvale, CA
COURTRIGHT, W. C.	Los Alamos Scientific Laboratory, NM
COWAN, G. H.	USAMC, Dover, NJ
COX, Z. J.	Deseret Test Center, Ft. Douglas, UT
CRAIG, E. L.	NWS, Concord, CA
CRENSHAW, CWO-2 L. E.	US NAVSTA, San Diego, CA

CRIST, F. H.	Tooele AD, Grantsville, UT
CROSS, J. F.	Hercules, Inc., Salt Lake City, UT
CRUSE, C. S.	Human Eng. Lab., Aberdeen Proving Ground, MD
CUNNINGHAM, LCDR J. F.	Pacific Missile Range, Pt. Mugu, CA
DAHLGREN, LCDR A. W.	EOD, Ft. Storey, VA
DAHN, R. C.	Albrook AFB, Canal Zone
DANIEL, MAJ B. M.	Lexington-Blue Grass AD, Richmond, KY
DAVIDSON, T. W.	USAMC, Redstone Arsenal, AL
DAVIES, CAPT H. E., Jr.	NOMTF, White Sands Missile Range, NM
DAVIS, J. O.	Sandia Laboratories, Albuquerque, NM
DAVIS, P. D.	NASA Hq, Washington, DC
DAVIS, MAJ R. S.	DCASR, Cleveland, OH
DAVIS, W. C.	Naval Ord. Systems Support Ofc. Pac., San Diego, CA
DAY, W. C.	USA Corps of Engineers, Livermore, CA
DEANS, H. L.	Hq USAMC, Washington, DC
DEESE, J. H.	NASA John F. Kennedy Space Center, FL
DEL REGNO, L.	DCASR, Dallas, TX
DEXTER, R. F.	Internal Revenue Serv., US Treasury, Washington, DC
DONAHUE, CAPT J. C.	USNAD, Crane, IN
DONALDSON, P. A.	NWC, China Lake, CA
DONLAN, CDR W. J.	Cruiser-Destroyer Force, USPF, San Diego, CA
DOSTER, 1LT D. C.	Eglin AFB, FL
DOWLEN, T. W.	Sierra AD, Herlong, CA
DOWLING, T. P.	Trojan US Powder, Allentown, PA

DOYLE, J. R.	Sandia Laboratories, NM
DRAKE, R. W.	Los Alamos Laboratory, NM
DREYER, O. F.	Lockheed Missiles & Space Co., Sunnyvale, CA
DUNN, D. J.	Aberdeen Research Center, BRL, MD
DUNN, M. L.	ASESB, Washington, DC
DUNNE, DR. B.B.	ABARIS Corp., Solana Beach, CA
DUNWOODY, C. C.	McChord AFB, WA
DUTY, R. R.	Ammo. Procurement & Supply Agency, Joliet, IL
ECKHAUS, S. R.	Chemical Process Lab, Edgewood Arsenal, MD
EDWARDS, MSgt B. A.	Dir. of Aerospace Safety, Norton AFB, CA
EDWARDS, D. W.	Trojan US Powder, Allentown, PA
EDWARDS, G. D.	NOSC, Washington, DC
EGAN, LTC T. F.	DCASR, Boston, MA
EHRINGER, A. G.	AMC, Savanna, IL
ELKINS, W. N.	White Sands Missile Range, NM
ELSASSER, F. M.	Travis AFB, Fairfield, CA
ELLIS, J. B.	RASA, Huntsville, AL
ENDSLEY, D. E.	IGDSOE, Norton AFB, CA
EPSTEIN, A.	Ft. Ord, CA
EVERETT, J.	SMAMA (IGYG), McClellan AFB, CA
FAIRCHILD, J. M.	AFPRO, Aerojet General Corp, Sacramento, CA
FARBER, DR. E. A.	University of FL, Gainesville, FL
FARMER, A. A.	Polaris Missile Facility Atlantic, Charleston, SC
FARMER, M. D.	Dir. for Distr. & Transp. Ammo. Div., Berea, KY

FEINSTEIN, D. I.	IIT Research Institute, Chicago, IL
FERRARO, C., Jr.	US Atomic Energy Commission, Albuquerque, NM
FERRIS, WO-1 J. A.	USS SPERRY AS12; FSPO San Diego, CA
FICHTER, F. C.	Lockheed Propulsion Co., Redlands, CA
FIDELL, F. J.	USA Frankford Arsenal, PA
FINE, W. T.	NOL, White Oak, MD
FLEMING, LCDR T. E.	COMCRUDESPAC, San Diego, CA
FLETCHER, DR. E. R.	Lovelace Foundation, Albuquerque, NM
FLYNN, COL N. C.	MAC, Scott AFB, IL
FORBES, F. S.	AFRPL, Edwards AFB, CA
FORSYTHE, F. J.	Joliet AAP, IL
FOWLER, W. T.	Radford AAP, VA
FREEDMAN, M.	McDonnel Douglas Astronautics, Titusville, FL
FRETTS, C. S.	MAC, McChord AFB, WA
GADDY, CDR J. K.	US Atomic Energy Commission, Wash., DC
GALLES, F. P.	Naval Torpedo Station, Keyport, WA
GAPPA, G. B.	NSC Point Loma Annex, San Diego, CA
GARDNER, B. D.	Riss International Corp., Kansas City, MO
GARRETT, LCDR L. E.	COMSERVLANT, Norfolk, VA
GIBBLE, J. W.	NASC, Washington, DC
GILMORE, A. E.	NAD, Crane, IN
GOFF, C. R.	Day & Zimmermann, Inc., Lone Star Div., Texarkana, TX
GOODWIN, V. K.	AFSC, Andrews AFB, Washington, DC
GORNALL, COL J. L.	IGDSOE, Norton AFB, CA
GOTT, R. W.	Hercules Incorporated, Wilmington, DE

GOULD, N. A.	AFPRO Rocketdyne Div., Canoga Park, CA
GRAHAM, E. L.	Joliet AAP, IL
GRAHAM, MAJ GEN E. M., Jr.	USAMC, Dover, NJ
GRANT, H. R., Jr.	Baggett Transportation Co., Birmingham, AL
GRAVES, CWO-4 B. B.	AFRPL, Edwards AFB, CA
GRAY, C. W.	Umatilla AD, OR
GRAY, MAJ J. D.	Ramstein, Germany
GREEN, J. F.	Naval Ord. Systems Support Ofc., Pacific, San Diego, CA
GREEN, R. H.	State of CA-Div of Hwys, Los Angeles, CA
GRIER, H. B.	DCASD, Pasadena, CA
GRIFFIN, MAJ J. H.	Kwajalein Missile Range, APO San Francisco, CA
GUARIENTI, R. P.	Lawrence Livermore Lab., Livermore CA
GULBRANSON, H. G.	Mo. River Div. CE, Omaha, NE
GUNN, CDR M. C., Jr.	NAS Norfolk, VA
GUNN, LTC W. E.	OOAMA, Hill AFB, UT
GUTIERREZ, W. J.	DCASR, Los Angeles, CA
HALL, P. H.	MAC, Charl[illegible] AFB, SC
HAMILTON, N. A.	Volunteer AAP, Chattanooga, TN
HAMMERLY, W1 G. T.	USN Amphibious Base, Coronado, CA
HAMMOND, J. W.	NASA, John F. Kennedy Space Center, FL
HAMPE, J. W.	Hq Aeronautical Systems Div., Wright-Patterson AFB, OH
HANEY, COL C. W.	Kirtland AFB, Albuquerque, NM
HANNA, R. J.	The Boeing Co., Seattle, WA
HANNAH, M. M.	Norton AFB, CA

[illegible]	[illegible]
HARDWICK, D. W.	Mason & Hanger-Silas Mason Co., Amarillo, TX
HARRISON, E. D.	Aberdeen R&D Center, MD
HART, R. E.	Bur. of Explosives, Assoc. American RR, San Francisco, CA
HARTMAN, F. X.	NASA, John F. Kennedy Space Center, FL
HASSLER, J. W.	Holex Inc., Hollister, CA
HAUCK, J.	SAMSO, LA AFS, El Segundo, CA
HAYDEN, W. G.	Olin Corp, East Alton, IL
HEALY, M. J.	Philco Ford, Newport Beach, CA
HEASTON, R. J.	Ofc. of the Chief of R&D, Wash., DC
HEDGES, D. L.	North American Rockwell, Los Angeles, CA
HEESEMAN, A.	Wyle Laboratories, Norco, CA
HELLE, C. J.	Remington Arms Co., Inc., Sao Paulo, S.P.
HELMS, E. D.	Holston AAP, Kingsport, TN
HENDERSON, F. G.	USAF, Norton AFB, CA
HERNDON, LTC J. E., Jr.	OTSG, DA, Washington, DC
HERMAN, R. C.	ASESB, Washington, DC
HICKS, V. N.	Picatinny Arsenal, Dover, NJ
HIGGINS, CDR W. H.	Cruiser Destroyer Force, Newport, RI
HILL, T. P.	Day & Zimmermann, Inc., Philadelphia, PA
HILL, W. V.	Black & Veatch, Kansas City, MO
HILLYER, COL W. K.	Hq USAF IGDA, Washington, DC
HINSON, P. C.	Mason & Hanger-Silas Mason Co. Inc., Burlington, IA
HODSON, P.	Safeguard System Command, Huntsville, AL

HOLBERT, A. P.	NWC, China Lake, CA
HONTGAS, C. P.	NWL, Dahlgren, VA
HORN, R. M.	The Marquardt Co., Van Nuys, CA
HOWARTH, E. S.	AFSC (IGFG), Andrews AFB, Wash., DC
HUGHES, G. F., Jr.	NWS, Yorktown, VA
HUNTER, B. H.	HQ AFCMD/SE, Los Angeles, CA
IRWIN, B. F.	Elmendorf AFB, Anchorage, AK
JENKINS, D. M.	USNWL, Dahlgren, VA
JERCINOVIC, L. M.	Sandia Lab., Albuquerque, NM
JOHNSON, C. N.	Tri-State Motor Transit Co., Joplin, MO
JOHNSON, G. W.	JERAC Corp., San Diego, CA
JOHNSON, I. R. E.	Polaris Missile Facility, Pacific, Bremerton, WA
JOHNSON, J. L.	AFCMD, Los Angeles, CA
JOHNSON, L. J.	NASA, Langley Research Center, VA
JOHNSON, L. G.	Olin Corp., Indiana AAP, Charlestown, IN
JOHNSON, R. K.	North Am. Rockwell Corp., Downey, CA
JONES, C. P.	NOSC, Washington, DC
JONES, D. J.	Talley Industries, Inc., Mesa, AZ
JONES, F. M.	Aerojet Solid Propulsion Co., Sacramento, CA
JORDAN, C. J.	USAMC Ofc. of the Surgeon, Washington, DC
JORDAN, CWO T. J.	USNS, Miramar, CA
JUSTUS, F.	USNAD Hawthorne, NV
KAPLAN, K.	URS Research Co., San Mateo, CA

KELLEY, H. L.	SAMSO, Los Angeles AFS, El Segundo, CA
KELLY, J. P. H.	USAEC, Washington, DC
KERVIN, T. L.	White Sands Missile Range, NM
KINDIG, LCDR J. N.	NASC, Washington, DC
KING, P. V.	General Electric Co., Bay St. Louis, MS
KINGERY, C. N.	BRL Aberdeen Proving Ground, MD
KINNEY, G. F.	NWC China Lake, CA
KNASEL, B. L.	ASESB, Washington, DC
KNOTT, E. F.	USNOTU, Patrick AFB, FL
KOCH, L. G.	Lockheed Propulsion Co., Redlands, CA
KOKINAKIS, W.	Ballistics Research Lab., Aberdeen, MD
KOMOS, J. N.	DCAS-QS, Cameron Station, Alexandria, VA
KOPP, DR. C. V.	NWL, Dahlgren, VA
KRIVULKA, COL R. L.	USAMR&D, Washington, DC
KURTH, E. H.	Hercules Inc., Wilmington, DE
LaFRENZ, LTC R. L.	USACE, Livermore, CA
LAKES, H. C.	Naval Undersea R&D Ctr., Pasadena, CA
LANCASTER, J. M.	Savanna AD, IL
LANDRUM, D.	American Farm Lines, Oklahoma City, OK
LARIMER, E. M.	Twin Cities AAP, MN
LARSON, R. A. N.	Naval Missile Center, Point Mugu, CA
LAVIN, CDR C. V.	ASESB, Washington, DC
LAWLER, CDR R. L.	USNAS North Island, San Diego, CA
LEACH, T. M.	NAVORDSYSCOM, Bloomington, IN
LEAPE, C. V.	Naval Ord. Systems Support Ofc., Pacific, San Diego, CA

LERWILL, R. J.	USA Test & Evaluation Command, Aberdeen Proving Ground, MD
LESLIE, E. B.	Anniston AD, Anniston, AL
LEVENS, E.	McDonnell Douglas Corp., Santa Monica, CA
LEVINE, D.	NOL, Silver Spring, MD
LEWIS, H.	E. I. du Pont de Nemours & Co. Inc., Carney's Point, NJ
LEWIS, H. L.	NOSSO Pacific, San Diego, CA
LIEBERMAN, P.	TRW Systems Group, Redondo Beach, CA
LIGON, R. L.	Martin Marietta Corp., Vandenberg AFB, CA
LOSS, E. T.	MTMTS-SS, Washington, DC
LOVELL, H. C.	Naval Station, Fire Dept., San Diego, CA
LOVING, F. A.	E. I. du Pont de Nemour & Co. Inc., Martinsburg, WV
LOWELL, J. W.	ASESB, Washington, DC
LUCKETT, R. G.	Yuma Proving Ground, AZ
LUCKY, V. M.	WAMTM&T Svc., Oakland, CA
LUSIS, I.	TRW Systems Group, Redondo Beach, CA
McBAIN, LTC G. D., Jr.	DCASR, Los Angeles, CA
McCOWEN, S. W.	SMAMA(IGYE), McClellan AFB, CA
McCULLOUGH, LT W. L.	White Sands Missile Range, NM
McDONALD, J. B.	Brunswick Corp., Sugar Grove, VA
McKAGUE, MAJ J. R.	DAMMO, Canadian Forces, Ottawa, Canada
McKEEN, W. P.	NAD, Crane, IN
McLELLAN, Q. A., Jr.	Harry Diamond Lab., Washington, DC

McLEOD, D. A.	Albuquerque Phoenix Express, Inc., Albuquerque, NM
McLEOD, D. K.	Albuquerque Phoenix Express, Inc., Albuquerque, NM
McSMITH, D.	NASA Langley Research Center, Hampton, VA
MAGUIRE, R. I.	AFRPL, Edwards AFB, CA
MAHONEY, G. T.	Huntsville Div., CE, Huntsville, AL
MANN, SW9 S.	USAASTA, Edwards AFB, CA
MAPLES, J. D.	USAMC, Redstone Arsenal, Huntsville, AL
MARCHITELLI, T. T.	NOSC, Washington, DC
MARSISCHRY, G. W.	NAVORDSYSCOM, Safety School, Bloomington, IN
MARYMEE, W. M.	DCASD-Phoenix, AZ
MATHIS, J. M.	Martin Marietta Corp., Vandenberg AFB, CA
MAXWELL, L. V.	USNAD, McAlester, OK
MENGLE, CDR K. J.	NAS North Island, San Diego, CA
METCALF, H. L.	OSD, Washington, DC
MICHAELSON, C. J.	Holex Inc., Hollister, CA
MILLER, B. L.	DSA, DCASD, Reading, PA
MILLER, R. J.	Uniroyal Inc., JAAP, Joliet, IL
MITCHELL, CWO 3 R. E.	USNS, San Diego, CA
MITCHELL, W. D.	Redstone Arsenal, AL
MOATS, CDR L. D.	USS KITTY HAWK CVA-63, FPO San Francisco, CA
MOLLOY, J. J.	N. American Rockwell Corp., El Segundo, CA
MONKS, R. E.	NWC, China Lake, CA
MOORE, S. R.	AMC, Redstone Arsenal, AL
MORAN, P. J.	Lockheed Missiles & Space Co., Santa Cruz, CA
MORE, W. M.	McGuire AFB, NJ

MORGAN, CWO 2 C. E.	PMR, Pt. Mugu, CA
MORRIS, C. S.	Tooele AD, UT
MORTENSEN, D. L.	USNAD, Hawthorne, NV
MULLEN, DR. R. K.	EG & G. Inc., Golet , CA
MULLINS, R. K., Jr.	Lawrence Livermore Lab., U of CA, Livermore, CA
MURPHY, H. J.	MTMTS, Newport News, VA
MURRAY, R.	Philco Ford, Newport Beach, CA
MYERS, R. L.	USA MCFSA, Charlestown, IN
NAPADENSKY, H. S.	IIT Research Institute, Chicago, IL
NEAL, R. E.	Jet Propulsion Lab., Pasadena, CA
NELSON, N. M.	Sandia Lab., Albuquerque, NM
NEUHART, V. M.	DCAS, San Diego, CA
NIEMITZ, J. J.	USNAD, Oahu, Hawaii
NOLAN, W. J.	USAMC, Picatinny Arsenal, Dover, NJ
NORRIS, LCDR F. C.	NAS, North Island, San Diego, CA
O'DEA, J. P.	Mason & Hanger-Silas Mason Co., Cornhusker AAP, Grand Island, NE
O'GRADY, F. R.	Hq USAF (IGDSOE), Norton AFB, CA
O'KELLEY, LT T. K.	Sandia Corp., Livermore, CA
OLDS, BG R.	Director of Aerospace Safety, Norton AFB, CA
OSHEROFF, CAPT B. J.	HEW, Washington, DC
OVERBEY, C. A.	NASA, John F. Kennedy Space Center, FL
OZBURN, J. E.	Leonard Bros. Trucking Co. Inc., Pensacola, FL
PAKULAK, J. M., Jr.	NWC, China Lake, CA
PALFEY, A. J.	The Dow Chemical Co., Midland, MI

PARKER, F. J., Jr.	Red River AD, Texarkana, TX
PARKS, D. K.	Falcon R & D Co., Denver, CO
PATALIVE, COL J. A. (Ret)	Huntington Beach, CA
PATTERSON, D. G.	AMC, Savanna, IL
PEACOCK, D. G.	NOS, Indian Head, MD
PEARSON, DR. G. S.	British Defense Staff, Washington, DC
PENA, A. O.	White Sands Missile Range, NM
PERKINS, R. G.	ASESB, Washington, DC
PETERSON, F. I.	Green Farm Test Site, San Diego, CA
PETES, J.	NOL, White Oak, MD
PHILLIPS, MAJ L. R.	DCASR, Los Angeles, CA
PITZER, J. M.	Umatilla AD, Hermiston, OR
PLATE, COL S. W. (Ret)	Tri-State Motor Transit Co., Arlington, VA
PLAUSON, R. A.	US NWC, China Lake, CA
PLEDGER, D. B.	NFEC, Yards & Docks Annex, Washington, DC
PRADE, CDR N. H.	NWS, Concord, CA
PRATT, V.	Deseret Test Center, Ft. Douglas, UT
PRESTERA, M. R., Jr.	Prestera Trucking Co., Huntington, WV
PRIOR, L. C.	Jet Propulsion Lab., Pasadena, CA
QUEEN, W. G.	AMCSF, Washington, DC
RACHEL, C. K.	Hughes Aircraft Co., Tucson, AZ
RAIFORD, J. P.	Offutt AFB, NE
RANDALL, H. J.	DCA, Burlingame, CA
RANES, W. A.	USNAD, Hawthorne, NV
RECTOR, R. L.	Western Div. Naval Facilities Eng. Com., San Bruno, CA

REED, CAPT W. F., Jr.	Ofc. of the Oceanographer of the Navy, Alexandria, VA
REGAN, L. F.	AMC, Washington, DC
REUTER, MAJ L. H.	USA Med. Research & Development Com., Washington, DC
REXON, LTC C. J., Jr.	DCASD, Anaheim, CA
REYNOLDS, CMSgt E. J.	DAF Hq, PACAF IGYW, APO San Francisco, CA
RHODES, COL C. W.	Hq ADC, EMMM, Ent AFB, CO
RHODES, D. B.	Lone Star AAP, Texarkana, TX
RICHARDSON, COL J. M. (Ret)	Louisiana AAP, Shreveport, LA
RICHARDSON, R. H.	Hercules Inc., Cumberland, MD
RICHMOND, D. R.	Lovelace Foundation, Albuquerque, NM
RICKS, LTC A. C.	SAFSP, Los Angeles, AFS, CA
RIGGS, W. A.	Lompoc Flight Svc. Inc., Lompoc, CA
RILEY, W. E.	SAMTEC, Vandenberg, CA
RINGENBERG, M. G.	Edgewood Arsenal, MD
RIVETT, P. G.	US NWC, China Lake, CA
ROACH, R.	NAPEC, NAC, Crane, IN
ROBBINS, R. G.	USADC, Ent AFB, CO
ROBERTS, C.	DCAS Van Nuys, Canoga Park, CA
ROBSON, B. P.	Atlantic Research Corp., Costa Mesa, CA
RODIO, P. A.	USAMC, Washington, DC
ROGERS, G. S.	NWS, Yorktown, VA
ROMESBERG, L. E.	Mechanics Research, Inc., Albuquerque, NM
ROOS, W. P.	NOSC, Washington, DC
ROSENTHAL, M.	TRW Systems Gp., Redondo Beach, CA
ROSER, E. G.	Eglin AFB, FL

ROSSER, T. B.	USAEWES, Vicksburg, MS
ROTHERY, C. M.	DCASR, St. Louis, MO
ROWLAND, S. W., Jr.	Gulf Energy & Environmental Systems, San Diego, CA
ROYLANCE, H. M.	NOSC, Washington, DC
RUBINSTEIN, L.	NASA, John F. Kennedy Space Center, FL
RUSSELL, B. A.	The Dow Chemical Co., Midland, MI
RUSSO, F.	S&H Trucking, Inc., Fontana, CA
SABATKE, E. O.	Anniston AD, Anniston, AL
SADWIN, L. D.	USNOL, White Oak, MD
SAHLIN, R. A.	Remington Arms Co., Bridgeport, CT
SAMS, J. J.	Bendix Launch Sup. Div., Kennedy Space Center, FL
SANDERS, R. M.	Safeguard System Command, Huntsville, AL
SANSON, J. H.	DCASR, Los Angeles, CA
SAVITT, J.	EXPLOSIFORM, Inc., Belvedere, CA
SCARFF, O. W.	Aberdeen R&D Center, Aberdeen, MD
SCHIFFMAN, DR. T. H.	Gen. American Research Div., Niles, IL
SCHIMMEL, R. T.	Picatinny Arsenal, Dover, NJ
SCHREYER, H. L.	Mechanics Research, Inc., Albuquerque, NM
SCOTT, DR. R. A.	ASESB, Washington, DC
SCHRODER, M. P.	AFPRO, Hughes Aircraft Co., Tucson, AZ
SEAVERS, R. H.	AMC, Huntsville, AL
SELLARS, CAPT R. F. (Ret)	Martin Marietta Corp., Orlando, FL
SEXTON, T. K.	SMAMA, McClellan AFB, CA
SHAFER, R. A.	Savanna AD, Savanna, IL
SHAW, LTC R. F., Jr. (Ret)	Twin Cities AAP, New Brighton, MN

SHEETZ, G. L.	NOSSO, Pacific, San Diego, CA
SHERIDAN, E. J.	Deputy Asst. Secretary of Defense(I&H), Washington, DC
SHINDLER, C. E.	Frankford Arsenal, Philadelphia, PA
SHOPHER, K. R.	AFLC, Wright-Patterson AFB, OH
SHORT, J. M.	Heavy Transport Inc., Long Beach, CA
SIMS, W. H.	NOSSO Atlantic Norfolk Naval Shipyard, Portsmouth, VA
SIRIANNE, R. A.	DCSL Dir. of Army Transportation, Washington, DC
SKAAR, K. S.	NWC, China Lake, CA
SLIGHT, G. E.	NAD Crane, IN
SLYKER, R. W.	Naval Missile Center, Pt. Mugu, CA
SMITH, E. L.	Travis AFB, Fairfield, CA
SMITH, G. L.	Remington Arms Co. Inc., Bridgeport, CT
SMITH, W. E.	NWC, China Lake, CA
SMYTHE, K. E.	Leonard Bros. Trucking, Los Angeles, CA
SNELLER, G.	Kelly AFB, San Antonio, TX
SPATES, R. M.	TRW Systems Gp., Redondo Beach, CA
SPEARS, C. L.	LTV Aerospace Corp., Dallas, TX
STACK, R. C.	Vanderberg AFB, CA
STARK, C. G.	Hq Comd USAF(IGY), Bolling AFB, DC
STARR, L. D.	NOSC, Washington, DC
STEVENS, C. J.	NFEC, Washington, DC
STEVENS, M. E.	DNA, Washington, DC
STOFFERS, F. W.	Jet Propulsion Lab., Pasadena, CA
STOREY, R. B.	DSPM Hill AFB, UT

STOUT, B. C.	Holloman AFB, NM
STRATTON, F. V.	Louisiana AAP, LA
STRANG, COL C. F.	Hq USAF IGDA, Washington, DC
STROKFIELD, E. E.	American Farm Lines, Oklahoma City, OK
SWANSON, L. H.	Jet Propulsion Lab., Pasadena, CA
SWATOSH, J. J.	IIT Research Institute, Chicago, IL
SYROP, L. J.	Explosive Technology, Fairfield, CA
TAKAHASHI, R. T.	SAC, Barksdale AFB, LA
TALLENT, CAPT C. R.	COMEODGRUONE, FPO San Francisco, CA
TEEL, G. D.	Ballistic Research Lab., Aberdeen, MD
TEICHMANN, E. C.	Hq USAREUR & 7th Army, Heidelberg Military, Germany
TEREO, M.	NAD Earle, NJ
THOMAS, W. C.	Naval Undersea R&D Center, San Diego, CA
THOMPSON, M. S.	Hq AF Eastern Test Range, Patrick AFB, FL
THOMPSON, R. N.	USNAD, Hawthorne, NV
THORNLEY, DR. G. M.	IRECO Chemicals, Salt Lake City, UT
THORPE, T. C.	USNWS, Seal Beach, CA
TINKER, W. L.	NS San Diego, CA
TODSEN, W. P.	USA Corps of Eng., Omaha, NE
TOMKINS, C. D.	Tomkins Flight Svc. Inc., Burlington, IA
TORZILLO, J. W.	Redstone Arsenal, AL
TOWNSEND, W. H.	Aberdeen Research Center, BRL, MD
TRAFTON, J. O.	GE Co., Burlington, VT
TUCKER, G. L.	NOSSO Pacific, San Diego, CA

VAN DOLAH, DR. R. W.	US Bureau of Mines, Pittsburg, PA
VAN PATTEN, E. W.	Munitions Command, Dover, NJ
VELEKER, LT D. L.	Naval Station, San Diego, CA
VESSELS, C. C.	Kwajalein Missile Range, Huntsville, AL
VICKERY, J. F.	Embassy of Australia, Washington, DC
VIHSTADT, E. A.	Louisiana AAP, Shreveport, LA
VOUGHT, W. H.	HEW, Washington, DC
WACHOB, CDR J. R.	DDC, Cameron Station, Alexandria, VA
WALKER, E. A.	Atomic Energy Commission, Miamisburg, OH
WALKER, R. C.	Bendix Launch Sup. Div., Kennedy Space Center, FL
WALL, M. F.	Thiokol Chemical Corp., Marshall, TX
WALLACE, COL R. D.	USAMC Ofc of the Surgeon, Washington, DC
WALSH, M. F.	NWS Concord, CA
WATKINS, C. R.	AF/PREES, Bolling AFB, DC
WATKINS, LCDR J.	NOEF, Keyport, WA
WATSON, R. R.	Explosive Storage & Transportation Committee, London W1, England
WEALS, F. H.	USNWC, China Lake, CA
WEHMHOENER, E. A.	Lake City AAP, Independence, MO
WEISS, H.	N. American Rockwell Corp., Canoga Park, CA
WELLS, F. B.	Picatinny Arsenal, Dover, NJ
WENZEL, A. B.	Southwest Research Institute, San Antonio, TX
WEST, F. L., Jr.	AFATL/DLGS, Eglin AFB, FL
WESTERVELT, CAPT J. D.	CNO, Washington, DC
WESTON, R. A.	Mission Airlines, Goleta, CA
WHEELOCK, H. R.	Wyle Lab., El Segundo, CA

WHITE, H. M.	AFRPL, Edwards AFB, CA
WIGGER, G. F.	OCE, USA, Washington, DC
WILLIAMS, R.	Harry Diamond Lab., Washington, DC
WILLIAMSON, T. G.	Boeing Seattle, Seattle, WA
WILLIS, F. M.	E. I. DuPont Co., Potomac River Dev. Lab., Martinsburg, WV
WILSON, D. E.	NOS Indian Head, MD
WILSON, J.	U. S. Naval Station, Miramar, CA
WILSON, P. D.	Pacific Missile Range, Point Mugu, CA
WILTON, C.	URS Research Co., San Mateo, CA
WINER, H.	Hq USA, ADC, Ent AFB, CO
WORKUM, A. D.	McDonnell Douglas Astronautics, Titusville, FL
YAGER, M. L.	Aerojet Ord. & Mfg. Co., Downey, CA
YOES, LCDR E. C.	Commandant, 11th Naval District, San Diego, CA
YOUNG, R. E.	Picatinny Arsenal, Dover, NJ
ZAKER, DR. T. A.	ASESB, Washington, DC
ZELLER, DR. A. F.	IGDSOE, Norton AFB, CA
ZELLMER, E. E.	The Boeing Co., AF Plant 77, Ogden, UT
ZIMMER, M. F.	Armament Lab., Eglin AFB, FL